Reporting on dissemination activities carried out within the frame of the Desire project

articles

Østergaard, Poul Alberg

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

Work Package 8 final report

Reporting on dissemination activities carried out within the frame of the DESIRE project

- Articles -

This report document the dissemination activities carried out within the framework of the DESIRE project. Being a dissemination project, the project has naturally had a very large focus on disseminating the knowledge of how renewable energy may me integrated into the energy systems by various means. The timing of the project has been very good in as much as fluctuating renewable energy resources are getting increased attention – politically as well as in terms of actual physical expansion, for which reason there is an increasing focus on how to integrate substantial amounts of fluctuating renewable energy.

The message has therefore also generally been received well, and the partners of the project have been very active in disseminating the knowledge in articles as well as meetings, seminars and conferences.

The contributions of the individual partners are ordered according to the following list of partners. Each contribution is documented in a dissemination report followed by the actual contribution where possible

1 Aalborg University, Sustainable Energy Planning Group
2 EMD International A/S
3 PlanEnergi
4 University of Birmingham
5 Institut für Solare Energieversorgungstechnik Verein an der Universität Kassel e.V. (ISET)
6 Universität Kassel
7 EMD Deutschland
8 Fundación Labein
9 Warzaw University of Technology
10 Tallin University of Technology

Poul Alberg Østergaard
Editor and Work Package Leader, WP8

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Henrik Lund, Aalborg University, Denmark Ebbe Münster, PlanEnergi, Denmark
E-mail	lund@plan.aau.dk
Title of dissemination	Integrated transportation and energy sector CO_2 emission control strategies
Type of activity	Article in peer-reviewed journal
Title of forum	Transport Policy 13 (2006), pp. 426-433
Language	English
Date of dissemination	May 22nd 2006
Place of dissemination	Worldwide
Brief abstract / description of dissemination activity	The main topic of the article is the integration of the transport and the energy sector in the case of Denmark. The article illustrates and quantifies the mutual benefits of integrating strategies for future energy and transport CO2 emissions control. Today, this issue is very relevant in Denmark due to the high share of fluctuating renewable energy produced in the country. In the future, such issue will apply to other countries that plan to use a high share of renewable energy. In short, the energy sector can help the transport sector to replace oil by renewable energy and CHP, while the transport sector can assist the energy system in integrating a higher share of intermittent energy and CHP. Two scenarios for partial conversion of the transport fleet have been considered. One is battery cars combined with hydrogen fuel cell cars, while the other is the use of biofuel (ethanol) and synthetic fuel (methanol) for internal combustion cars. An increase in the fraction of electricity delivered by fluctuating sources like wind power will lead to excess electricity production, and the two scenarios have a substantial effect on the decrease of the excess production.
Audience impact assessment	The article is directed at the international research society and is expected to have a large impact on the development of new strategies in the energy and transport sectors.
Dissemination	Included after this form Also available via http://www.sciencedirect.com

ELSEVIER

Transport Policy 13 (2006) 426–433

TRANSPORT POLICY

www.elsevier.com/locate/tranpol

Integrated transportation and energy sector CO_2 emission control strategies

Henrik Lund[a,*], Ebbe Münster[b]

[a]Department of Development and Planning, Aalborg University, Fibigerstraede 13, 9220 Aalborg, Denmark
[b]PlanEnergi s/i, Jyllandsgade 1, 9520 Skørping, Denmark

Available online 22 May 2006

Abstract

This paper analyses the mutual benefits of integrating strategies for future energy and transport CO_2 emissions control. The paper illustrates and quantifies the mutual benefits of integrating the transport and the energy sector in the case of Denmark. Today this issue is very relevant in Denmark due to the high share of fluctuating renewable energy produced in the country. In the future, such issue will apply to other countries who plan to use a high share of renewable energy. In short, the energy sector can help the transport sector to replace oil by renewable energy and combined heat and power production (CHP), while the transport sector can assist the energy system in integrating a higher degree of intermittent energy and CHP. Two scenarios for partial conversion of the transport fleet have been considered. One is battery cars combined with hydrogen fuel cell cars, while the other is the use of biofuel (ethanol) and synthetic fuel (methanol) for internal combustion cars. An increase in the fraction of electricity delivered by fluctuating sources like wind power will lead to excess electricity production and the two aforementioned scenarios have a substantial effect on the decrease of the excess production.

Keywords: CO_2 emission; Transport; Renewable energy

1. Introduction

Most governments distinguish between the transport and the energy sector, when making strategies for the implementation of CO_2 emissions controls. In the energy sector, measures such as energy conservation and renewable energy are very often proposed (Lund, 1999a, b; Lund et al., 1999, 2000, 2003, 2005; Maeng et al., 1999; Ostergaard, 2005), while in the transport sector, most countries experience a steady growth in oil consumption without being able to implement measures to stop the growth (Johansson, 1998; Lund, 2000; Ono, 1993; Ramanathan and Parikh, 1999; Stead, 2001). Measures to decrease oil consumptions and CO_2 emissions in transportation are almost always seen separately from the energy sector (Kiang and Schipper, 1996; Litman, 2005; Sperling, 2001; Stead, 1999; Taylor and Ampt, 2003). This paper analyses the mutual benefits of integrating future energy and transport control strategies for CO_2 emissions.

When the Danish Parliament in 1990 defined the first objectives of CO_2 emissions controls, the target was formulated as a 20% cut in year 2005 compared with year 1988. Additional targets have been added for year 2030 and the Kyoto Protocol Period (2008–2012). In the implementation strategies, the energy sector is expected to provide for most of the cut in CO_2 emissions (Danish Government, 1996). Moreover, the targets for the transport sector have been adjusted several times, because Denmark has failed to implement suitable policies. And today the transport strategy is part of a policy in which the Danish government plans to make use of the Kyoto mechanisms of Joint Implementation or Clean Development Mechanism.

However, the energy and the transport sectors are facing two very different challenges today. The transport sector is in a situation in which oil consumption should be decreased, and no politically acceptable strategies have been found so far. One perspective would be to introduce electric vehicles and hydrogen vehicles or to replace petrol

*Corresponding author. Tel.: +45 9635 8309; fax: +45 9815 3788.
E-mail address: lund@plan.aau.dk (H. Lund).

0967-070X/$ - see front matter
doi:10.1016/j.tranpol.2006.03.003

by ethanol and methanol. On the other hand, the energy sector in Denmark has implemented wind power and combined heat and power production (CHP) to a degree which now causes an integration problem. Time differences between demand and supply simply force the system to produce excess electricity.

Fig. 1 illustrates the problem by showing the electricity balance of West Denmark (Jutland and Funen) for a typical 24-h period. It is seen how an excess electricity production takes place, because the wind turbines produce according to the wind, the CHPs produce according to the heat demand, and the power plants must keep a certain minimum fraction of the production for stability and regulation purposes. Such issues, which are now faced by Denmark, will in the future apply to other countries who plan to use a high share of fluctuating renewable energy sources.

The purpose of this paper is to illustrate and quantify the mutual benefits of integrating the sectors of transport and energy. In short, the energy sector can help the transport sector to replace oil with renewable energy and CHP. The transport sector, on the other hand, can help the energy system by integrating a higher degree of fluctuating renewable energy and CHP.

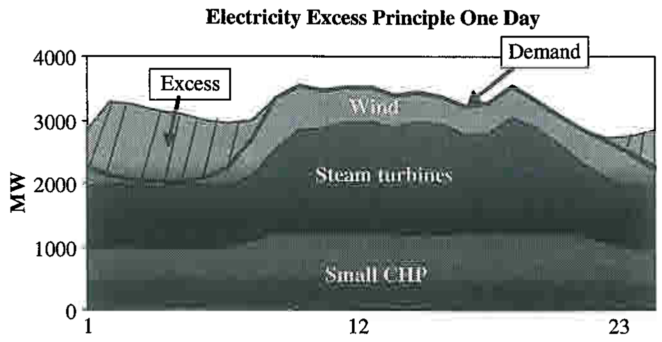


Fig. 1. Principle diagram of the excess electricity production problem.

2. Energy system analysis methodology

The large-scale integration of wind power has been analysed by use of the EnergyPLAN computer model. The western Danish collective energy system (electricity and district heating) has been modelled for the year 2020, including the implementation of the Nord Pool market. The EnergyPLAN model is a deterministic input/output simulation model. General inputs are demands, capacities and a number of optional different regulation strategies, emphasising import/export and excess electricity production. Outputs are energy balances and resulting annual production, fuel consumption and import/export. For a detailed description of the model, please consult (Lund et al., 2004; Lund and Münster, 2003).

The energy system in the EnergyPLAN model includes heat production of solar thermal, industrial CHP, CHP units, heat pumps and heat storage and boilers (see Fig. 2). District heating supply is divided into three groups of boiler systems and decentralised and centralised CHP systems. Additional to the CHP units, the systems include electricity production from renewable energy, i.e. photovoltaic and wind power input divided into onshore and offshore, as well as traditional power plants (condensation plants).

The model is simple in the respect that it aggregates all units in the modelled region into one unit with average properties in each of the mentioned types. This means that the differences among the single units and the transmissions among them are not considered. On the other hand, the model is advanced in the respect that it uses detailed hourly distributions of heat demands, electricity demands,

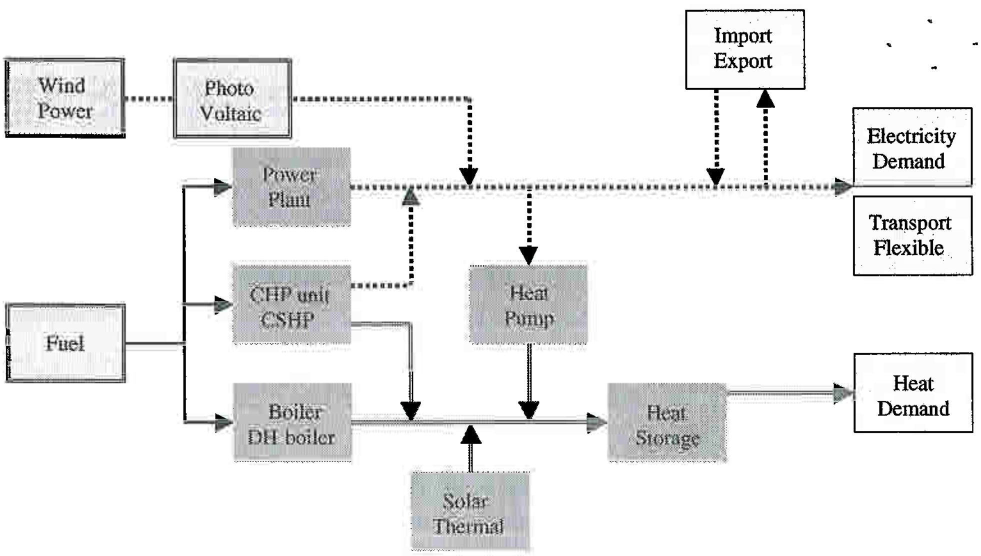


Fig. 2. The EnergyPLAN computer model Principle Energy System. CHP and CSHP, combined heat and power production plants and DH, district heating.

wind production etc., to analyse the behaviour of the entire system hour by hour for a whole year. Various constraints, operational strategies and changes to the system can be imposed and compared.

The model requires four sets of input for the technical analysis.

- The first set is the annual district heating consumption, and the annual consumption of electricity, including flexible demand and electricity consumption of the transport sector, if any.
- The second set is the capacity and the yearly distribution of renewable energy sources such as photovoltaic and wind power. This part also defines solar thermal and industrial CHP heat production inputs to district heating.
- The third set consists of capacities and operation efficiencies of CHP units, power stations, boilers, and heat pumps.
- The last set specifies some technical limitations; namely the minimum CHP and power plant percentage of the load needed in order to retain grid stability. Furthermore, it includes the maximum heat pump percentage of the heat production needed in order to achieve the specified efficiency of the heat pumps.

For the economic calculations of exporting and/or importing electricity, the model needs input to define price variations on the international electricity market. The model has an internal hour by hour standard price variation based on historical data from the Nord Pool market. These price variations can be adjusted by the following inputs:

- a multiplication factor,
- an addition factor (€/MWh),
- an adjustment price of non-predictable export/import,
- a factor expressing the market reaction to wind and CHP (price elasticity).

Such factors have been used for implementing the model of Nord Pool as described in (Lund and Munster, 2006). The price elasticity factor used is 3 €/MWh/GW. The price level on the Nord Pool spot market and the function of the bottlenecks on the international transmission lines are heavily influenced by the water level of the Norwegian and Swedish hydro power reservoirs. In the following, all economic calculations are made as averages on a 7-year period consisting of one dry year, three normal years and three wet years (Norsk Olie- og Energidepartment, 2001).

Furthermore, input is needed in terms of marginal production fuel costs. In accordance with the expectation of the Danish Energy Agency (Danish Energy Agency, 2003), the following prices for 2020 have been used in the reference calculation: 1.8 €/GJ coal, 4.0 €/GJ oil, 3.7 €/GJ Natural gas and 3.2 €/GJ for biomass (straw).

The model emphasises the consequences of different regulation strategies. Basically, the technical analyses distinguish between the two following strategies:

Regulation Strategy I: Meeting Heat Demand. In this strategy, all units produce solely according to heat demands. In district heating systems without CHP, the boiler simply supplies the difference between the district heating demand and the production of solar thermal and industrial CHP. For district heating with CHP, the units are given priority according to the following sequence: Solar thermal, industrial CHP, CHP units, heat pumps, and peak load boilers.

Regulation Strategy II: Meeting both Heat and Electricity Demands. When choosing strategy II, the export of electricity is minimised mainly by replacing CHP heat production by boilers or by the use of heat pumps. This strategy simultaneously increases electricity consumption and decreases electricity production, as the CHP units must decrease their heat production. By the use of extra capacity at the CHP plants combined with heat storage capacity, the production at the condensation plants is minimised and replaced by CHP production.

In the economic analysis, the two strategies mentioned above are moderated by a market trade strategy based on the principle of exporting when the market prices are higher than the marginal production costs, and importing when they are lower than the marginal production costs. In all strategies, the model takes a number of restrictions and limitations into consideration, such as:

- the system needs a certain degree of grid-stabilising capacity,
- bottlenecks in external transmission capacity,
- strategies for avoiding critical surplus production,
- maximum percentage of heat production from heat pump.

2.1. Reference energy system

The western part of Denmark has been chosen as a reference scenario for the year 2020. The region is identical to the area of the transmission system operator Eltra. This reference scenario is based on the ELTRA system plan 2001. It was used in 2001 in the work of an expert group who, on request of the Danish Parliament, investigated the problem of large-scale integration of wind and analysed possible means and strategies for managing the problem (Danish Energy Agency, 2001). As part of the work, Aalborg University made a series of long-term 2020 energy system analyses of investments in more flexible energy systems in Denmark (Lund and Münster, 2001).

The reference was constituted by the following development: the Danish electricity demand was expected to rise from 35.3 TWh in 2001 to 41.1 TWh in 2020 equal to an annual rise of approximately 0.8%. The capacity of installed wind power in 2001 was expected to rise from

570 to 1850 MW in East Denmark and from 1870 to 3860 MW in West Denmark in 2020. The increase is primarily due to the implementation of one 150 MW offshore wind farm each year. Existing large coal-fired CHP steam turbines are replaced by new natural gas-fired combined cycle CHP units when the lifetime of the old CHP plants expires.

2.2. Reference and alternative regulation systems

The reference regulation system has been defined as the present regulation adjusted by a number of likely measures to avoid critical excess production. Thus, the reference regulation can be described in the following way:

- All wind turbines produce according to the fluctuations in the wind.
- All CHP plants produce according to the heat demand.
- Only the large power stations participate in the task of balancing supply and demand and securing grid stability.
- Minimum 300 MW and minimum 30% of the production must come from grid-stabilising power stations.
- Critical excess production is avoided by using the following priorities: (1) replacing CHP with boilers, (2) using electric heating and (3) if necessary, stopping the wind turbines.

In Lund and Munster (2006), the ability of the reference system to integrate wind power has been compared with a number of alternative flexible regulation systems based on the following principles:

- CHP units operate in order to integrate wind power by reducing their electricity production in hours of excess production. Instead a boiler, and/or electric heating, and/or a heat pump replace the heat production.
- Small CHP units are included in the grid stabilisation task.

The feasibility of such flexible energy systems has been evaluated on its ability to exploit the Nord Pool market. The following set of assumptions has been created to generate a likely reference development:

- marginal wind production costs of new offshore wind farms 29 €/MWh,
- international CO_2 trade price in 2010–2020: 13 €/MWh.

Especially one alternative proved to be very efficient and cost-effective, namely the investment in heat pumps in combination with the above-mentioned change in regulation of the CHP plants. In the following, the heat pump alternative has been combined with two transport system scenarios.

2.3. Transport system scenarios

In order to investigate the influence of a possible electrification of part of the transport system on the existing electrical system, two scenarios have been established for the year 2020.

One is based on a research project carried out by Risø National Laboratory with the title: 'Electric Vehicles and Renewable Energy in the Transport Sector—Energy System Consequences' (Nielsen and Jørgensen, 2000). This report concludes that the technical performance—in particular the range—of battery cars and hydrogen fuel cell cars will gradually improve in the coming decades, making it feasible for these types of cars to take over a substantial part of the transport task, particularly for passenger cars and small delivery vans below 2 t. Fuel cell cars operating on synthetic fuels like methanol are left out because of a poorer overall efficiency.

The scenario shown in Fig. 3 below is scaled down in order to fit to West Denmark only. The scenario assumes a 27% substitution of passenger cars and small vans based on internal combustion engine (ICE) by battery cars combined with a 14% substitution by hydrogen-operated fuel cell cars in 2020. The batteries of the cars are assumed to be large enough to level out consumption on a 24-h basis (loading during the night), while the combined H_2 storage of the electrolyser plants and the cars is considered capable of levelling out consumption on a four-week basis. The electrolysers are dimensioned to operate app. 4000 h/year.

The heat produced by the electrolysers is not considered in the model. If the electrolysers are placed close to CHP plants, the produced heat may have a positive effect on the balance in the grid, because heat will be produced in periods when the system needs to increase electricity consumption. If the produced heat is used by the district heating network it will result in a lower heat—and hence electricity—production of the CHP plant. This effect cannot be modelled by the present version (6.5) of the EnergyPLAN model, but is considered for the next version.

An alternative scenario based on liquid fuels (biofuels and synthetic fuels) used by internal combustion engine cars is presented in Fig. 4. This scenario is based on the REtrol-vision of the Danish power company ELSAM (ELSAM, 2005). It has been scaled to provide the same

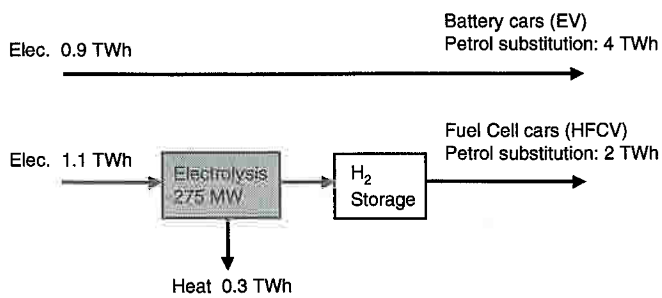


Fig. 3. Transport scenario #1.

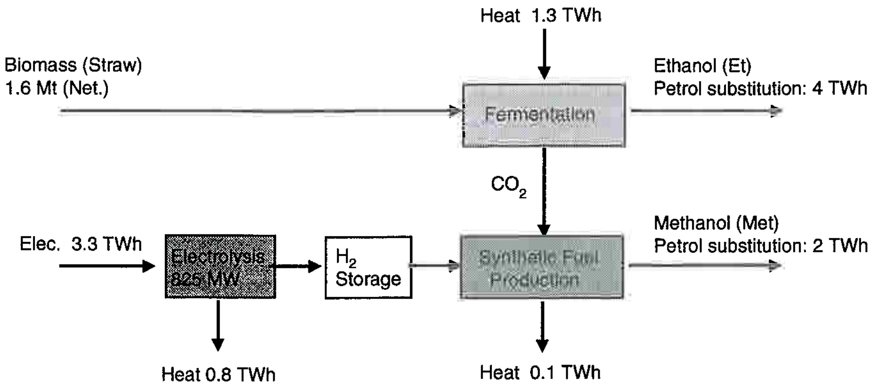


Fig. 4. Transport scenario #2.

petrol substitution as scenario #1. It is seen that is has a lower overall efficiency, but it cannot be directly compared to #1 because it assumes the use of ICE-based cars, which are either standard cars (low percentage mix of Et or Met with petrol) or slightly converted cars (higher percentages mix). Hence, the total costs of the system including conversion of the fleet are much lower.

In this case, the heat balance is negative (because the heat produced by the internal combustion engines of the cars is not considered). The consumed heat is provided as waste heat from condensing power plants. An important asset of this scenario is that the ethanol fermenters produce the carbon needed for the production of methanol. In this way, the total system, including the cars, can be regarded as CO_2 neutral. Apart from ethanol the fermenter produces a solid biofuel. This fuel has been subtracted in the biomass input. Like in #1, the electricity consumption of the electrolysers is assumed to be flexible to the extent that it can level out electricity consumption on a 4-week basis.

3. Results

3.1. Excess electricity production

The first comparison depicted shows the ability to decrease the excess electricity production caused by wind power by the various systems considered. The 'Ref' curve of Fig. 5 shows how most of the wind power electricity in 2020 must be exported from West Denmark if the reference regulation method described in Section 2.1 is used. Note that 25 TWh of wind power correspond to 100% of the electricity demand of West Denmark. If 350 MW-electric heat pumps are established at the CHPs and the alternative regulation method is used, the situation will improve considerably.

If transport scenario #1 (EV/HFCV) is introduced instead it will have more or less the same effect. Transport scenario #2 (Et/Met) has a larger impact because it uses more electricity. A combination of the heat pumps and scenario #2 is only marginally better because the constraint

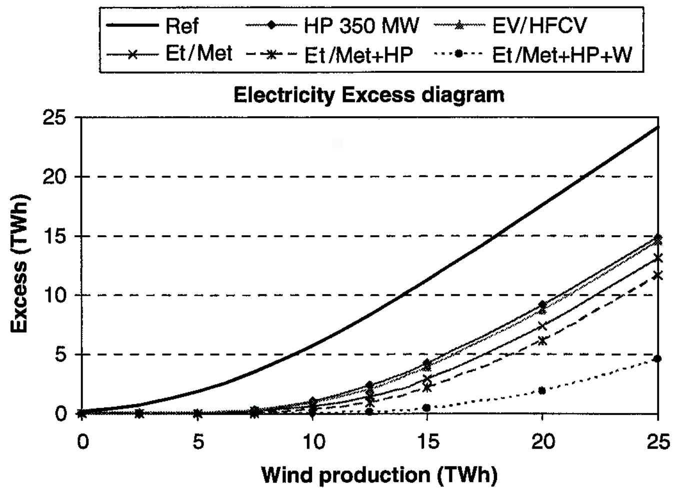


Fig. 5. Excess electricity diagram (HP, heat pump).

of the minimum fraction of power plants for stabilising purposes puts a limit to the regulation possibilities.

If this constraint is eased by assuming that 50% of the wind turbines are supplied with advanced high-voltage semiconductor regulation equipment, making it possible for them to perform phase and frequency regulation, the situation will again improve considerably. (Et/Met + HP + W). This type of equipment is available today and it is considered economically feasible for the very big offshore turbines that will be established in the future. It is particularly relevant for the combination wind turbine/electrolyser, because this combination can perform both up and down regulations when both parts are active.

3.2. Socio-economy

In the former section, it was seen how the electrification of part of the transport fleet could improve the ability of the energy systems to incorporate wind turbines. In this section, the involved socio-economy will be discussed. It is noted that the costs of the conversion of the transport system itself are not considered. We restrict ourselves to

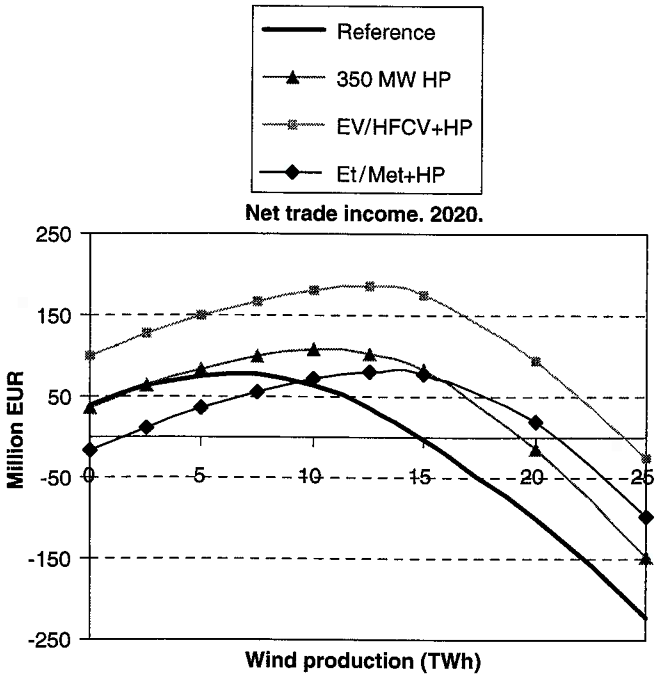


Fig. 6. Net trade income in West Denmark, 2020 (HP, heat pump).

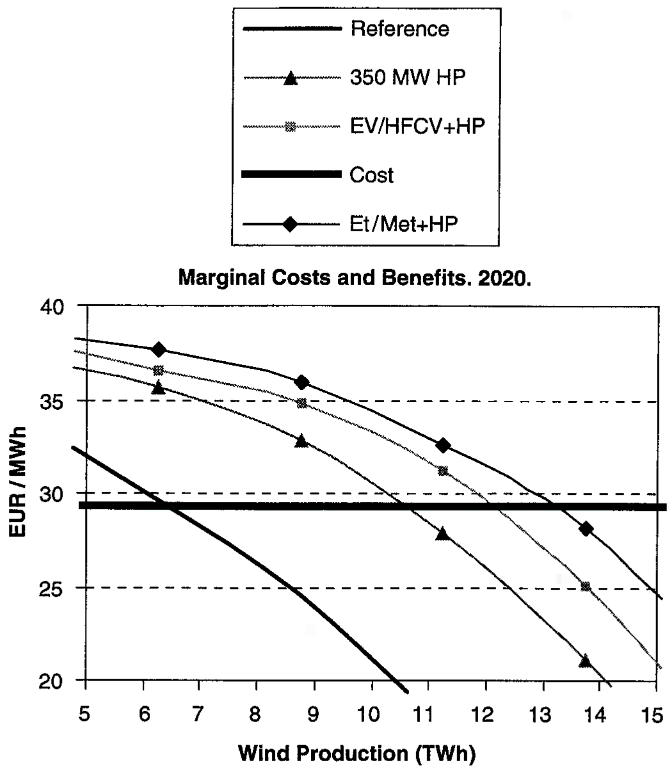


Fig. 7. Marginal costs and benefits for West Denmark, 2020 (HP, heat pump).

looking at the economic consequences of such conversions on the rest of the energy system.

Fig. 6 illustrates the ability of the different systems to trade on the Nord Pool market. The figures in the graph are relative to a situation with no wind power and no trading. In the reference situation, wind power above 6–7 TWh/year starts to decrease and above 15 TWh/year even causes a negative net result for West Denmark because the marginal value of each MWh produced cannot finance the costs of establishing and operating the wind turbine. Adding 350 MW of heat pumps improves this situation considerably. The costs of this investment are included.

Combining the heat pumps with the two transport scenarios further moves the optimum for wind power to the right. The vertical position of the curves for the transport scenarios should not be emphasised since the costs of converting the cars and establishing the distribution systems are not included. The reason for the scenario #2 to have lower incomes than #1 is mainly the fact that it involves the use of biomass, the costs of which are included in the model. This problem is avoided in Fig. 7, which shows the marginal benefits of adding extra wind power to the system.

In this figure, it is seen how the optimal amount of wind production increases when the flexibility of the system increases (note the different scaling from Fig. 6). Optimal wind production moves from about the present situation for the reference system to 40 and even to 50% of the demand when heat pumps and transport electrification are assumed. Scenario #2 has the highest optimum because it uses more electricity than #1.

3.3. CO_2 emissions

In this section, the impacts of the various systems on the CO_2 emissions of West Denmark in 2020 are calculated. The calculations extend to the total energy system including the part of the transport fleet involved in the two transport scenarios (app. 40% of the cars below 2 t).

Fig. 8 shows how the total emissions from the considered part of the energy system decrease when wind production increases to a certain level. This level represents the previously mentioned constraint of the minimum fraction of power to be produced by central power plants. Adding flexibility means reducing CO_2 emissions because the electricity production of coal-fired power plants is reduced. The scenario #1 is slightly better that #2 because of the higher overall energy efficiency of this scenario.

In this calculation, no corrections are made due to export and import of electricity. As the export increases significantly with higher wind productions it may become relevant to make such corrections. Very complicated simulations of the entire electrical system of Northern Europe are needed to make such corrections accurately, but it is possible to get a fairly good estimate of the result by using simple key figures of CO_2 emissions for marginal MWh in Denmark's neighbouring countries. In Fig. 9 below, the following figures have been assumed:

- For normal and dry years: 0.5 t/MWh.
- For wet years: 1 t/MWh (Lund and Munster, 2006).

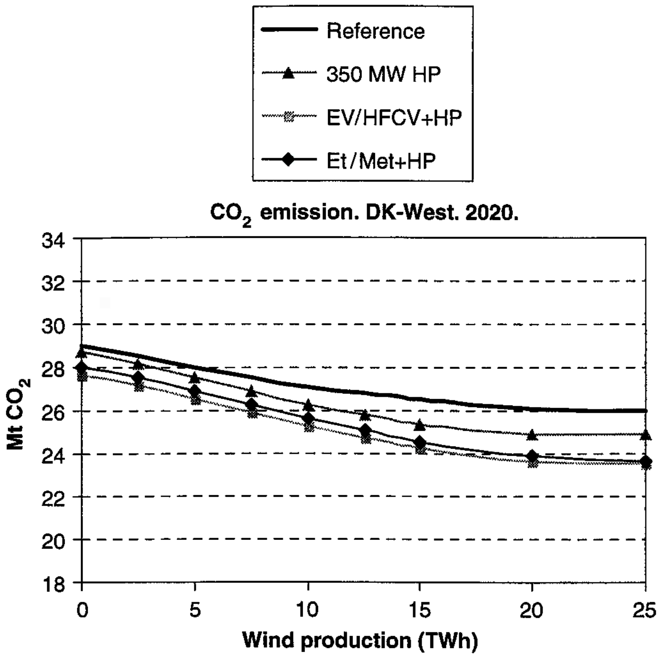


Fig. 8. CO_2 emissions from West Denmark, 2020 (HP, heat pump).

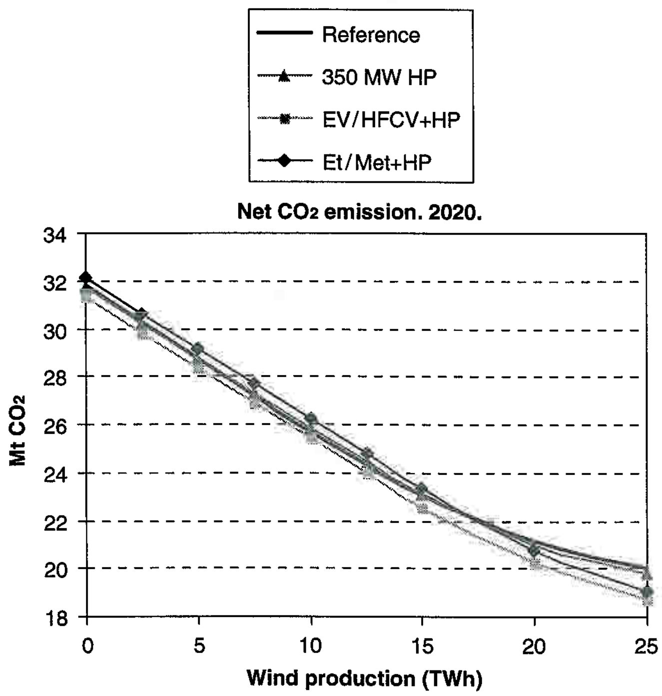


Fig. 9. Net CO_2 emissions for West Denmark, 2020 (HP, heat pump).

Not surprisingly, this figure shows the benefits to the global CO_2 emissions of adding wind turbines in Denmark. It also shows that it makes little difference for these emissions whether we use electricity for cars in Denmark or export the electricity to be used for substitution of coal or gas somewhere else. It should, however, be noted that the flexibility-adding measures discussed in the preceding sections are necessary to facilitate high wind power fractions. It should also be noted that the demand for 'clean' electricity by our neighbours only lasts until they convert their own systems, and that the shown increase in export of electricity assumes a substantial increase in the transmission capacity of the international power lines connecting Denmark to Norway, Sweden and Germany.

4. Conclusion

In the calculations, two scenarios for partial conversion of the transport fleet have been considered:

#1: Battery cars combined with hydrogen fuel cell cars.
#2: Use of biofuel (ethanol) and synthetic fuel (methanol) for internal combustion cars.

In both cases, the substitution of app. 40% of petrol consumption for cars below 2 t is assumed in 2020. The overall efficiency of case #1 is better than case #2, but this is in the actual Danish case compensated by the use of biomass and surplus heat from power plants. As a result, the CO_2 emissions savings are the same for the two cases. Both scenarios have a substantial effect on decreasing the excess electricity production caused by a possible increase in the fraction of electricity delivered by fluctuating sources like wind turbines. In a situation in which 50% of the electricity production is fluctuating, both scenarios decrease the excess electricity production by app. 70%. The decrease is much bigger than the actual amount of electricity used for transport because of the ability of this particular demand to be placed at the critical hours.

The total economy of conversion of the fleet has not been calculated, but the positive effects on the economy of the rest of the energy system have been evaluated.

It is shown how the use of electricify for transport increases the optimal amount of wind turbines in West Denmark. While the establishment of 350 MW-e heat pumps at the cogeneration plants (CHP) increases this optimum from app. 25% to app. 40% in 2020, the additional electrification of the transport fleet further increases the optimum to app. 50%.

Calculations on CO_2 balances show that the two scenarios cause a saving of app. 1 Mt CO_2 for West Denmark. If the indirect CO_2 savings in the neighbouring countries caused by export of electricity is considered, it is, however, shown that the above-mentioned facilitation of an increase of the amount of wind turbines causes bigger savings (app. 2 Mt).

Today this issue is very relevant in Denmark due to the high share of fluctuating renewable energy. In the future, such issue will apply to other countries who plan to use a high share of renewable energy.

Acknowledgement

The findings in this paper are part of the results of the EU-funded DESIRE project (Dissemination Strategy on Electricity balancing for large Scale Integration of Renewable Energy). Preliminary results were presented and discussed at the Risø International Energy Conference May 2005 in Roskilde, Denmark.

References

Danish Energy Agency, 2001. Rapport fra arbejdsgruppen om kraftvarme- og VE-elektricitet (Report from the expertgroup on CHP- and RES-electricity). Danish Energy Agency, Copenhagen.

Danish Energy Agency, 2003. Brændselsprisforudsætninger.

Danish Government, 1996. Energy 21, The Danish Government's Action Plan for Energy. Ministry of Environment and Energy, Copenhagen.

ELSAM, 2005. REtrol (VEnzin) vision. www.elsam.com

Johansson, B., 1998. Will new technology be sufficient to solve the problem of air pollution caused by Swedish road transport? Transport Policy 5 (4), 213–221.

Kiang, N., Schipper, L., 1996. Energy trends in the Japanese transportation sector. Transport Policy 3 (1&2), 21–35.

Litman, T., 2005. Efficient vehicles versus efficient transportation: comparing transportation energy conservation strategies. Transport Policy 12 (2), 121–129.

Lund, H., 1999a. A green energy plan for Denmark—job creation as a strategy to implement both economic growth and a CO_2 reduction. Environmental & Resource Economics 14 (3), 431–439.

Lund, H., 1999b. Implementation of energy-conservation policies: the case of electric heating conversion in Denmark. Applied Energy 64 (1–4), 117–127.

Lund, H., 2000. Choice awareness: the development of technological and institutional choice in the public debate of Danish energy planning. Journal of Environmental Policy & Planning 2, 249–259.

Lund, H., Münster, E., 2001. AAU's analyser (Aalborg University Analyses). In: Danish Energy Agency (Ed.), Bilagsrapport fra arbejdsgruppen om kraftvarme- og VE-elektricitet (Attachment report from the expertgroup on CHP- and RES-electricity). Danish Energy Agency, Copenhagen, pp. 35–50.

Lund, H., Münster, E., 2003. Modelling of energy systems with a high percentage of CHP and wind power. Renewable Energy 28 (14), 2179–2193.

Lund, H., Munster, E., 2006. Integrated energy systems and local energy markets. Energy Policy 34 (10), 1152–1160.

Lund, H., Hvelplund, F., Kass, I., Dukalskis, E., Blumberga, D., 1999. District heating and market economy in Latvia. Energy 24 (7), 549–559.

Lund, H., Hvelplund, F., Ingermann, K., Kask, U., 2000. Estonian energy system—proposals for the implementation of a cogeneration strategy. Energy Policy 28 (10), 729–736.

Lund, H., Hvelplund, F., Nunthavorakarn, S., 2003. Feasibility of a 1400 MW coal-fired power-plant in Thailand. Applied Energy 76 (1–3), 55–64.

Lund, H., Münster, E., Tambjerg, L., 2004. EnergyPLAN, Computer Model for Energy System Analysis, version 6.0 Division of Technology, Environment and Society, Department of Development and Planning, Aalborg University. http://www.plan.auc.dk/tms/publikationer/workingpaper.php

Lund, H., Siupsinskas, G., Martinaitis, V., 2005. Implementation strategy for small CHP-plants in a competitive market: the case of Lithuania. Applied Energy 82 (3), 214–227.

Maeng, H., Lund, H., Hvelplund, F., 1999. Biogas plants in Denmark: technological and economic developments. Applied Energy 64 (1–4), 195–206.

Nielsen, L., Jørgensen, K., 2000. Electric vehicles and renewabele energy in the transport sector—energy system consequences. Risø National Laboratory, Roskilde.

Norsk Olie- og energidepartment, 2001. St. meld. nr. 37: Om vaskrafta og kraftbalancen.

Ono, Y., 1993. Japan's sustainable transport policy towards the 21st century. Transport Policy 1 (1), 32–42.

Ostergaard, P.A., 2005. Modelling grid losses and the geographic distribution of electricity generation. Renewable Energy 30 (7), 977–987.

Ramanathan, R., Parikh, J.K., 1999. Transport sector in India: an analysis in the context of sustainable development. Transport Policy 6 (1), 35–46.

Sperling, D., 2001. Public-private technology R&D partnerships: lessons from US partnership for a new generation of vehicles. Transport Policy 8 (4), 247–256.

Stead, D., 1999. Relationships between transport emissions and travel patterns in Britain. Transport Policy 6 (4), 247–258.

Stead, D., 2001. Transport intensity in Europe—indicators and trends. Transport Policy 8 (1), 29–46.

Taylor, M.A.P., Ampt, E.S., 2003. Travelling smarter down under: policies for voluntary travel behaviour change in Australia. Transport Policy 10 (3), 165–177.

Dissemination strategy on Electricity balancing
DESIRE
large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Niels I. Meyer, Aalborg University
E-mail	nim@byg.dtu.dk
Title of dissemination	Learnings from Wind Energy Policy in EU, With Focus on Denmark, Sweden and Spain.
Type of activity	Article in peer-reviewed journal (submitted)
Title of forum	GIN Wind Stream Conference, Cardiff, July 2006 The article is submitted for publication in the journal *European Environment.*
Language	English
Date of dissemination	03-07-2007 (Original conference presentation)
Place of dissemination	Worldwide
Brief abstract / description of dissemination activity	The paper describes the learnings from different wind energy policies in EU and compares the Danish development to that in Sweden and Spain. It is concluded that liberalisation of the electricity market in EU has created a number of problems for the promotion of wind power and for the establishment of a sustainable energy development in general.
Audience impact assessment	The message of the paper was well received and gave rise to a broad discussion at the session.
Dissemination	Included after this form

August 17, 2006

Adjusted paper for the GIN Wind Stream Conference, Cardiff, July 2006.

LEARNINGS FROM WIND ENERGY POLICY IN EU, WITH FOCUS ON DENMARK, SWEDEN AND SPAIN.

Dr. Niels I. Meyer, Technical University of Denmark

Contact details:

NIELS I. MEYER
Department of Civil Engineering
Technical University of Denmark
Brovej building 118
Telephone: +45 45 25 19 30
Email: nim@byg.dtu.dk

Abstract:

Promotion of wind power in Europe has been pioneered by Denmark, where wind power now covers about 20% of the total electricity consumption. The paper relates this result to the early Danish development of wind turbine technologies back in the 1890s and to the continued development during the following century leading to the start of the modern phase of wind power in the 1970s.

The successful promotion of Danish wind power in the last two decades of the 20th century is related to a number of factors including individual entrepreneurs, broad public support, early official certification of wind turbines, systematic government support of various types and co-operative private ownership of wind turbines.

The development of Danish wind power since 2000 has been influenced by liberalization of electricity markets in the EU and by new market oriented policies introduced by a liberalistic-conservative Danish government since 2002.

The paper describes the learnings form different policies and compares the Danish development to that in Sweden and Spain. It is concluded that liberalization has created a number of problems for the promotion of wind power and for the establishment of a sustainable energy development in general.

INTRODUCTION

Energy has become an important political point on the agenda of most countries in the World. This is due to a number of factors including lack of long-range supply security, the approaching ”oil peak” and the consequences of global warming from emission of greenhouse gases. Strangely enough, these problems were not in focus during the negotiations leading to the liberalization of electricity markets in the EU (European Communities, 1997). The consequences and problems were not analyzed in depth before it was decided to go along with the liberalization. Instead, the main focus was on obtaining lower consumer prices through stronger market competition.

After about 10 years of experience with the liberalized electricity markets serious problems have started to appear. The long-range supply security is at stake, environmental problems and technological innovation get lower priority in the electricity sector, and the same applies to maintenance of the grids. In addition, the creation of a few dominating utilities tend to reduce effective competition.

A basic problem is that sustainable energy development requires planning horizons of 40 to 50 years while the time horizon of commercial markets typically is an order of magnitude lower. Short-sighted commercial investments will often block the introduction of supply systems which are more environmental benign, have higher supply security and are less costly in the long run. Wind power and other supply systems based on renewable energy sources are typical examples of such favorable long range solutions.

Recently the EU Commission has suggested an evaluation of the possible role of nuclear power in the future supply system. This proposal is supported by the nuclear lobby in spite of a number of unsolved security and other types of problems including safe deposit of high-radioactive waste for thousands of years and limited cheap uranium sources partly in unstable regions of the world.

The economic cost of nuclear power is claimed by the nuclear industry to be less than 3 eurocents/kWh but this is a distorted number as it does not include all externalities, e.g. full insurance cost, realistic assumptions in relation to removing of old plants, hidden state subsidies through cheap investment loans and export credits etc. Over the years the EU has subsidized nuclear power by more than 60 billion euros. The real cost of electricity from nuclear power including all externalities could well be at least 50% higher than the postulated 3 eurocents/kWh.

It should also be mentioned that it poses severe problems to combine a substantial amount of nuclear power with a substantial amount of wind power and decentralized CHP in the same system. These technologies require different system structures in order to operate in an economic and controlled way. The introduction of nuclear power e.g. in the Danish supply system would imply a phase-out of the present development of a sustainable supply system based on wind power and decentralized CHP.

The present market system where important externalities from fossil fuels and nuclear plants have not been fully internalized distorts the competition to the disadvantage of sustainable supply systems based on renewable energy. Despite of that, the EU summit in March 2006 argued for more market influence in the energy sector as a way to diminish the increasing dependence on imported fossil fuels from politically unstable regions in the World.

This paper will document that long-range governmental planning and regulation has been essential for the promotion of wind power in Europe and thus for increasing the supply security and reducing the dangers of global warming. The energy policies in Denmark, Sweden and Spain are used as case studies in relation to promotion of wind power.

DANISH WIND ENERGY POLICY

The modern Danish wind energy policy should be seen on the background of a long historical development. The leading role of Denmark in promotion of wind power from the 1970s may be traced back to the pioneering work of Poul la Cour at Askov Folkes High School in the 1890s (Grubb and Meyer, 1993; Meyer, 1995).

La Cour developed and built a wind turbine for electricity production with a rotor diameter of 22 m including mechanical speed control. He even tested a number of rotor profiles in wind tunnels and provided energy storage based on hydrogen produced by electrolysis of water. The hydrogen was subsequently used for lighting purposes. He deserves the credit of initiating modern wind power development - including hydrogen as an energy carrier based on renewable energy sources (RES).

The concepts and technologies developed by la Cour provided a basis for wind electrification in Denmark during the first two decades of the 20th century. In 1918, 120 rural wind power stations were established with rated turbine powers between 20 and 35 kW, yielding a total installed wind capacity of about 3 MW compared to a total Danish electricity capacity of about 80 MW. With the typical capacity factors of that time, this corresponds to around 3% coverage by wind of the Danish electricity demand in 1918. Even to-day only three nations (Denmark, Germany and Spain) have exceeded this coverage by wind.

During the following four decades, wind turbines were further developed and tested in Denmark and elsewhere, especially in Germany, UK and USA. This period culminated with the 200 kW Gedser Mill in Denmark, in operation from 1959 to 1967. The operation was successful, and the Gedser Mill became the mother of modern Danish wind turbines in the 1970s characterized by three blades on a horizontal axis in an upwind position.

This concept was further developed by a number of small Danish industrial entrepreneurs from the mid seventies starting with small turbines typically with rated power of about 22 kW. Most of these small firms were economically weak and only few of them survived in the long run. However, the wind power development attained early support from the Danish Academy of Technical Sciences (Danish Academy, 1975 and 1976) and from governmental support programs including a test and certification facility. The Danish utilities were also involved in a few programs in the seventies but were generally skeptical concerning the future of Danish wind power.

Energy Plans and Nuclear Debate in Denmark

The decade from the mid seventies to the mid eighties was characterized by strong debates and controversies over Danish energy policy. In the center of this debate was the question of nuclear power. The official energy policy was aiming at the introduction of nuclear power as soon as possible in the Danish supply system. This was an essential element in the first official energy plan from the spring of 1976 (Danish Ministry of Industry and Commerce, 1976).

An alternative energy plan without nuclear power and with a higher contribution from RES was published in the fall of the same year by a group of energy experts from Danish universities (Blegaa et al., 1976). A summary in English of the alternative energy plan was published in 1977 (Blegaa et al., 1977).

The opposition to nuclear power was also taken up by two new NGOs: the Organisation against Nuclear Power (OOA) and the Organisation for Renewable Energy (OVE) that were established in the mid seventies. These organizations soon became quite professional in their arguments about safety problems and other problems related to nuclear power – and in their arguments in favor of RES. It was surprising, however, to follow the style of argumentation by some of the leading Danish engineers and physicists in favor of nuclear power. They often used discriminating personal attacks on opponents to nuclear power who were accused of planning to overthrow the democracy in Denmark and to bring the Danish society back to the stone-age (Beuse et al., 2000).

In 1979 a new Ministry of Energy was established, and the minister published a second official energy plan in 1981 (Danish Ministry of Energy, 1981). Again the introduction of nuclear power was an essential element in this plan. Two years later a group of energy experts from Danish universities published another alternative energy plan without nuclear power and with emphasis on energy conservation and RES (Hvelplund et al., 1983). This plan was based on detailed models for the potential of energy conservation and also introduced new scenario methodologies. The alternative plan got broad attention through co-operation with the two active NGOs (OOA and OVE).

The history of nuclear power in Denmark was terminated in 1985 when the Danish parliament decided that nuclear power should not be an element of Danish energy supply. It should be noted that this was one year before the Chernobyl accident. The decision was influenced by several factors, but there is no doubt that the alliance between independent university experts and competent NGOs in connection with broad information campaigns on alternative possibilities was one of the factors.

After the termination of the nuclear debate, Danish energy policy was getting ripe for more focus on RES in the electricity supply system.

Shifting Danish Energy Policies

A significant shift in the focus of Danish energy policy took place towards the end of the eighties and was confirmed by a new official energy plan in 1990. Now the overall goal of Danish energy policy was to create a sustainable energy development and to comply with commitments to reduce greenhouse gas emission in an effort towards the mitigation of climate change. This has been manifested through the two latest official Danish energy plans from 1990 and 1996 (Danish Ministry of Energy, 1990; Danish Ministry of Environment and Energy, 1996). These policy plans strongly pursued continuity in their priorities on the development of RES and the expansion of electricity generation based on renewable energy sources (RES-E). The primary focus was on increasing the share of wind and biomass in electricity production. The specific target for RES in these plans is 12-14% of primary energy by year 2005 and 35% coverage by year 2030.

Wind power was given an important role in these plans with targets for installed capacity of around 1,500 MW in 2005 and 5,500 MW in 2030, covering 10% and up to 50% of Danish electricity consumption respectively (dependent on future development of electricity demand). The 2030 target includes 4,000 MW offshore wind capacity.

The 2005 target was already exceeded by a factor of two by 2003 where the installed wind power capacity was around 3,000 MW. Since then the installed capacity has stagnated and in early 2006 the coverage by wind is about 20% with an installed capacity of about 3,100 MW.

The net increase in Danish wind capacity in the last years with overall stagnation have mainly been due to a repowering scheme from 1999. According to this scheme turbines with rated capacities less than 100 kW could be replaced by three times the discarded capacity, while turbines between 100 and 150 kW could be replaced by twice the capacity until the end of 2003. The new turbines were given a premium of 0.17 DKK/kWh (2.3 eurocents/kWh) on top of the ordinary tariff for wind electricity. Although this scheme was supposed to stop by the end of 2003, dispensation has been given for turbines installed even in 2005 in order to counteract the trend of stagnation.

A new repowering programme beginning in January 2005 is supposed to add further 350 MW wind capacity on land. Turbines of less than 450 kW capacity are entitled to take part in this programme. In addition to the market price and an environmental bonus of 1.3 eurocents/kWh, wind power producers will receive a repowering subsidy of 1.6 eurocents/kWh. So far, a number of investors seem to adopt the strategy to buy the small turbines and to let them continue their production until major repairs are needed before they take advantage of the repowering scheme.

A coverage by fluctuating wind power of more than 20% of the total electricity consumption gives rise to new regulation problems, especially in combination with a high percentage of heat-bound co-generation like in Denmark. There have already been periods in Jutland with very strong winds where the total electricity production could not be taken up by the system in West Denmark.

The simple solution is to export the surplus electricity production to Northern Germany. However, this will often result in low prices for the exported electricity as Northern Germany also has a high density of wind power and the wind blows at approximately the same speed north and south of the boarder. In a longer perspective increasing exports will require expensive expansions of the high voltage transmission lines.

The Danish Energy Authority and the system operators are presently sponsoring a number of research projects investigating alternative solutions where wind farms and decentralized CHP-plants are included in the regulation of the overall system balance.

An international pilot project is taking place in western Denmark where the system presently contains approximately 3,500 MW of centralised (large) CHP, 1,600 MW of local CHP and 2,400 MW of wind power capacity. The project involves the development of a "Cell Architecture" for decentralized grid management of semi-autonomous cells with well-defined local functions and system-wide coordination capabilities (Lund et al., 2006).

A cell is defined as the part of a distribution system below a 150/60 kV substation typically consisting of 20-100 MW of conventional loads and a mix of CHP and wind turbine generators. The ambition is to develop a cell structure, where the cell disconnects itself from the high voltage grid and transfers to controlled island operation in case of a regional emergency situation reaching the point of no return. A less ambitious goal of the project is to secure that the cell black-starts itself to a state of controlled island operation after a total system collapse.

A distribution company in western Denmark has agreed to be part of the pilot project and a suitable 60 kV cell of that company has been selected as the pilot cell. The actual pilot implementation and testing of the cell controller in a selected part of the pilot cell is expected to be accomplished during 2006 and 2007 (Lund et al., 2006).

Danish Strategies for Wind Power Promotion

The Danish strategy for promotion of wind power in the period from the mid seventies to the mid nineties has combined a number of different elements:

- long-term government support for research, development and demonstration;
- national tests and certification of wind turbines;
- government sponsored wind energy resource surveys (wind atlases);
- subsidies, feed-in tariffs and regulations;
- local ownership of wind turbines and careful selection of sites.

These element will be discussed in more detail in the following.

Research, development and demonstration

In 1982 a government committee was established for promoting energy systems based on RES, including wind, solar and biomass. The members of the RES-Committee were experienced experts within these fields. After a few years of introductory work, the committee has had an annual budget of about 4.6 million euros where an appreciable part has been spent on development and demonstration of wind technologies. In the late eighties, the committee promoted new programs of offshore wind farms in order to overcome the foreseen obstacles for land based turbines and Denmark has been first in the world to establish large offshore wind farms.

The Danish development has followed a safe technical path, with a gradual increase in turbine size based on improvements of the same basic design. This development is illustrated in Table 1.

Year	1978	1983	1985	1988	1991	1995	1999	2005
Typical rated power of new turbines, kW	20-40	55-75	100-150	200-250	300-450	500-700	1000-1500	2000-3000

Table 1. Development of rated power for commercial Danish wind turbines. Numbers refer to the typical capacity range installed in a given year.

In addition to wind technology the committee was supporting development and demonstration of biogas systems based on animal manure, new processes for gasification of straw, efficient solar collectors and a number of other RES systems. Support was also given to market penetration in the form of information campaigns and the establishment of a number of local energy offices for promotion of RES.

The work of the committee was discontinued in 1991 in connection with a restructuring of the government committees in the field of RES. The total funding for RES from the committee during its nine years of operation amounted to about 30 million euros.

National Tests and Certification of Wind Turbines

It is important for a new and vulnerable industry as wind turbine manufacture in the late seventies and early eighties to acquire a credible market reputation from the beginning. For this reason a machine-testing program was established at Risø National Laboratory in 1978. About a year later, a formal certification procedure was added. This program has been essential in preventing sub-standard technologies from being marketed both at home and abroad.

A contrasting experience was reported from California in the early eighties, where generous federal tax credits combined with state incentives, provided large subsidies for wind installations. Entrepreneurs responded rapidly by constructing small-scale wind farms with 50 to 200 kW turbines, bringing California into the forefront with respect to the quantity of installed wind power. Unfortunately, many of the early machines installed in California were of poor quality and broke down during the first season of operation. The Danish turbines in California, however, distinguished themselves by credible operation due to the testing procedure at Risø National Laboratory.

Wind energy resource surveys

Wind resources are complex, and meteorological data on wind speeds are generally too inadequate to identify the potential wind power production with the necessary accuracy at a given site. It is important in this context to keep in mind that wind power varies as the cube of the wind velocity. As a consequence, national resource studies are crucial to wind energy penetration.

In 1981, a wind atlas for Denmark was published, based on the pioneering work of E. L. Petersen and co-workers at Risø National Laboratories (Petersen et al., 1981). Computational procedures described in the atlas make it possible to estimate the wind distribution over inhomogeneous terrain, taking into account topographical and shelter effects. The atlas may be used in wind power assessments at specific sites, and the methodology has been refined and computerized so that customers may have detailed information concerning expected electricity production for a specific turbine at their site.

An extensive national assessment study on sites for wind turbines was carried out in the period from 1981 to 1986 by Danish energy and environmental authorities (Danish Energy Authority, 1986). The assessment was based on turbines with a rated capacity of 2.5 MW each and led to a total production of 3 TWh per year from wind power if the potential was to be fully utilized. This would correspond to about 10% of the total electricity consumption at that time.

The assessment was obviously on the pessimistic side due to the questionable assumption of using only 2.5 MW turbines on land-based sites. The actual development has shown how misleading such assessments may be. The production from land-based wind power in year 2005 was about 7 TWh covering around 20 % of the total Danish electricity consumption.

Subsidies, feed-in tariffs and regulations

From 1979, private citizens who installed wind turbines were reimbursed 30% of the turbine's purchase price by the Danish government. Only turbines tested and certified by the Wind Test Station at Risø National Laboratory were eligible for this subsidy.

As wind power economy was improving during the eighties, the investment subsidy was gradually reduced to 10%. In 1989 it was finally eliminated after a total investment subsidy of about 280 million DKK (38 million euros) contributing to the installation of about 300 MW rated wind power.

Danish utilities had little experience in handling dispersed, small-scale electricity systems such as wind turbines when the modern phase of wind power was developing in the late seventies and early eighties. The utilities had been focusing on large-scale conventional power generating systems. As a consequence, most Danish electric utilities were highly skeptical about wind power, and they were not interested in offering favorable feed-in (pay-back) prices for wind electricity.

On this background the promotion of wind power would need either government regulations including favorable feed-in tariffs or voluntary agreements between utilities and wind power producers. In accordance with Danish traditions, the process started out by relying on voluntary agreements.

Already in the late seventies the first agreement was set up between the Association of Danish Electric Utilities on the one side, and the Danish Wind Power Association together with Danish wind turbine producers on the other side. This agreement was renegotiated several times during the period up to 1992 due to pressure from the wind power producers.

After a number of disagreements, especially over conditions for grid connections of wind power, the Danish government in 1992 introduced regulations for these conditions and for the feed-in tariff, which was fixed at 85% of the utility production and distribution costs. On top of the feed-in tariff from the utilities, the private wind power producers would receive a "tax refund" of 0.27 DKK per kWh (3.7 eurocents per kWh). This may be regarded as a premium due to the environmental benign nature of wind power.

As an example, a typical remuneration for wind power in the years after 1992 would amount to about 0.60 DKK per kWh (8 eurocents per kWh), which corresponds to a return on the investment of 10 to 15% (after tax). This remuneration was high enough to yield a strong growth in land-based wind capacity in the rest of the nineties as illustrated in Fig. 1.

Fig. 1. Development of installed Danish wind capacity from 1980 to 2002 (Danish Energy Authority).

Local Ownership of Wind Turbines and Careful Planning of Sites

The problem of visual pollution is hard to tackle because it is a matter of taste. Most people are quite happy to look at wind turbines, but a few people hate the turbines and have organized themselves to fight wind power. Public attitude surveys of wind power in the nineties have generally shown that around 80% of the Danish population supports wind power (Danish Wind Industry, 1993; Damborg, 2003).

The high acceptance of wind turbines in Denmark is to a large extent due to the fact that the majority of the Danish turbines are owned by private households based on neighborhood co-operatives. About 150,000 Danish households were registered as owners of shares in wind turbines in 2001. It is much easier to accept some extra noise and the view of a turbine if it reminds you of the fact that the turbine gives you money when the wind blows. The noise problem is, however, of minor importance for modern turbines when combined with regulations of minimum distances from dwellings.

There is no simple rule to indicate the optimum density of wind turbines when taking into account the environmental concerns of the population. The Danish experience seems to indicate that it depends both on the type and size of turbines, the organization of ownership and the rate of penetration. In addition, the acceptance is increased when the turbines are placed with consideration of the landscape and when aesthetical turbine designs are used.

In the early nineties, politicians in local communities were increasingly influenced by loud speaking groups opposing wind energy. This resulted in rather restrictive local policies towards sites for wind turbines, and the annual increase in wind capacity dropped from about 80 MW during the period 1990-92 to about 30 MW in 1993 and 1994.

In order to counteract this development, the Ministry of Environment and Energy ordered all Danish municipalities to estimate their potential for wind turbine sites and to report the results by June 1995. Not all municipalities were meeting the deadline, but the initiative by the Ministry did make an impact as may be seen from Fig. 1.

Wind Turbines as an Export Industry

In 2005, Danish wind turbine producers had a turnover of about 22 billion DKK (3 billion euro) with more than 90% of this coming from export covering nearly 40% of the world market for wind turbines. The direct employment in Danish wind industry is 6,600 people. Including sub-suppliers, the total employment related to wind industry is estimated at around 21,000 people.

Today, wind turbines are the third largest Danish export industry with significant contributions both to the balance of pay and to the global environment. This is in striking contrast to the pessimistic evaluation of the wind industry potential by engineers from Danish utilities and the nuclear establishment 20 years ago (Beuse et al., 2000).

Offshore Wind Farms in Danish Waters

Offshore wind farms are considered as a promising solution in relation to site constraints on land for countries with long coastlines and shallow waters like the UK, Ireland, Denmark, Sweden and Finland. Other countries with long coastlines like France, Portugal, Italy and Greece may have problems with deep waters close to the shore.

The first offshore wind farm in the World was made operational in September 1991 at a site northwest of the island of Lolland in the Baltic Sea. The wind farm consists of eleven 450 kW turbines positioned in two rows at water depths between 2 and 6 meters. The distance from shore varies from 1.2 km to 2.4 km, while the distance between turbines is about 300 meters.

The second offshore wind park was made operational in October 1995. It is sited at Tunø Knob in the sea between Jutland and the island of Samsø. The total capacity is 5 MW based on ten 500 kW turbines. A special investigation concerning the impact on bird habitats has been carried out in connection with the Tunø Knob project. This problem has turned out to be negligible.

Since that a number of Danish offshore wind farms have been installed as indicated in Table 2.

Year	**Place**	**Rated capacity**	**Number of turbines**	**Total capacity**
1991	Vindeby	450 kW	11	5 MW
1995	Tunø Knob	500 kW	10	5 MW
2001	Middelgrunden	2 MW	20	40 MW
2002	Horns Reef	2 MW	80	160 MW
2003	Rødsand	2.3 MW	72	165.6 MW
2003	Paludans Flak	2.3 MW	10	23 MW
2003	Rønland	2/2.3 MW	8	17.2 MW
2003	Frederikshavn	2.3/3 MW	4	10.6 MW
2003	Grenaa Harbour	2.75 MW	3	8.25 MW

Table 2. Offshore and near-coast Danish wind farms.

There was an agreement between the previous Danish social-democratic government and Danish utilities that they shall establish five wind farms each with a capacity of 150 MW before year 2008.

The sites for these five offshore farms have been decided and the first farm was in operation in late 2002 at Horns Reef in the North Sea. With its installed capacity of 160 MW it was the largest offshore wind farm in the world. The farm is expected to produce at least 0.6 TWh in an average wind year corresponding to at least 3750 hours at rated capacity. The salty environment in the North Sea has, however, given rise to a number of technological problems for the offshore farm at Horns Reef. After replacement of sensitive parts and extra precautions against corrosion these problems seem to have been solved – but at a high cost.

In 2003 number two of the planned large offshore wind farm was installed in the Baltic Sea at Rødsand 10 km south of Nysted city on the island of Lolland. This wind farm has not had the same technological problems as the Horns Reef farm.

After the change of government in Denmark in December 2001 the fate of the last three of the planned offshore farms has been uncertain. This has subsequently been resolved by an agreement in the Danish parliament in March 2004 including the large majority of the political parties. According to this agreement two new offshore wind farms each of 200 MW total rated capacity shall be installed before 2007 based on a tender procedure. The tender is supposed to include favourable conditions in relation to grid connections and guaranteed tariffs. The first tender for a new 200 MW wind farm at Horns Reaf in the North Sea has resulted in a tariff of 0.53 DKK/kWh (7.1 eurocents/kWh).

Conservative evaluations have concluded that there exists a total potential for offshore wind electricity production in Danish waters of at least 20 TWh per year, corresponding to nearly two thirds of the electricity consumption foreseen in year 2030. Thus, the technical wind resources do not constrain the fulfilment of the target for wind power in Denmark.

Shift in Economic Support Scheme

A new Danish energy act was confirmed in June 1999 which introduced a shift from the previous feed-in scheme to a proposed special market for trade in green certificates in combination with consumer quotas for green electricity specified by the government. In this model RES-E producers would receive a tariff consisting of the market price for electricity plus the selling price of the green certificate. The Danish government was inspired to make this shift by an expectation that the feed-in scheme would not be accepted by the EU Commission in the long run where the Commission would prefer a scheme with more market features (Danish Energy Authority, 2001). Decisions by the EU Commission in December 2005 have, however, postponed a harmonization of national support schemes, until more experience has been obtained in practice in relation to the different schemes. Thus, the Danish policy decision in 1999 was premature and based on wrong assumptions in this context.

The trading of green certificates was originally planned to start in January 2000, but owing to a number of complications related to the operational principles of the system including high transaction costs at a small national market, the Danish government has postponed the starting date of trading several times. It now appears that the trading of green certificates in Denmark is postponed into an uncertain future. As a consequence of this, a complicated set of transitional rules for RES-E has been introduced in the Danish system (Danish Ministry of Economy and Trade, 2003; Meyer and Koefoed, 2003).

The Danish transition from the original feed-in scheme to the planned certificates trading model has introduced so much uncertainty for private wind power investors that installation of new land-based capacity dropped from above 600 MW in 2000 to about 100 MW in 2001. This down-word trend has continued in the following years except in 2002 where a 160 MW offshore wind farm was installed at Horns Reef in the North Sea. The stagnation has been reinforced by the market oriented energy policy of the incoming conservative-liberalistic government in 2001 as illustrated in Fig. 2. Danish wind energy producers are now receiving the lowest price among the old 15 Member States of EU.

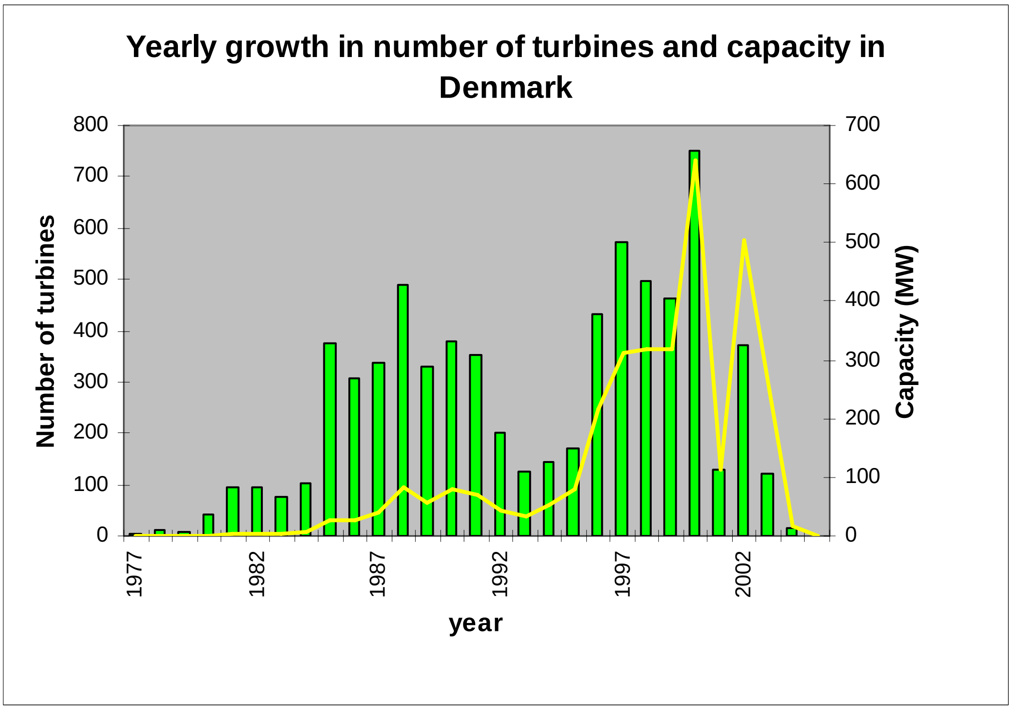


Figure 2. Yearly growth in number of turbines in Denmark (columns) and annual installed capacity (curve) from 1977 to 2004.

The net increase of wind capacity in 2005 and the first three months of 2006 has been close to zero. This is a striking illustration of the influence of national energy policy.

SWEDISH WIND ENERGY POLICY

The Swedish energy policy has been very different from the Danish policy both in relation to choice of technology and in relation to organisation and funding principles. From the seventies the Swedish government and Swedish turbine manufacturers have focused on large machines (larger than 1 MW) with two blades. At the same time the governmental wind energy policy has been expressed in vague terms with no precise indications of the operational tools.

The economic government support in Sweden was mainly used to develop and demonstrate two large turbines with a rated capacity of 2 MW and 3 MW owned by the utilities Vattenfall and Sydkraft. These machines never reached the state of mass production. The Swedish government tried to place the responsibility for the national wind power expansion in the eighties with some of the large utilities but they were not committed to this job at that time and the total installed wind capacity in Sweden was less than 7 MW in 1988. In contrast to this policy, the Danish development was based on a relatively large number of private entrepreneurs marketing small turbines and systematically increasing the turbine size as learning experience was gained.

Another barrier for the Swedish development has been the complicated, slow and bureaucratic local permit procedures. The Swedish legal system does not allow legally binding national or regional plans for wind power expansion. Instead general guidelines have been used with the first one from 1995 and with subsequent improvements in 2002 and 2003.

As a result of the different policies the market development for wind came much later in Sweden than in Denmark and the installed wind capacity in Sweden is still much smaller than in Denmark as illustrated in Fig. 3 – despite comparable wind potentials in the two countries. In the spring of 2006, however, Mona Sahlin, Swedish Minister for Sustainable Development has announced that the Swedish government's aim is to free the nation's economy of fossil fuel use by 2020. This ambitious goal would involve a rapid implementation of more RES such as wind and biomass.

A detailed analysis of the Swedish development from 1975 to 2000 has been given by Åstrand and Neij (2006). A summary of the main points of Swedish wind development is given in the following.

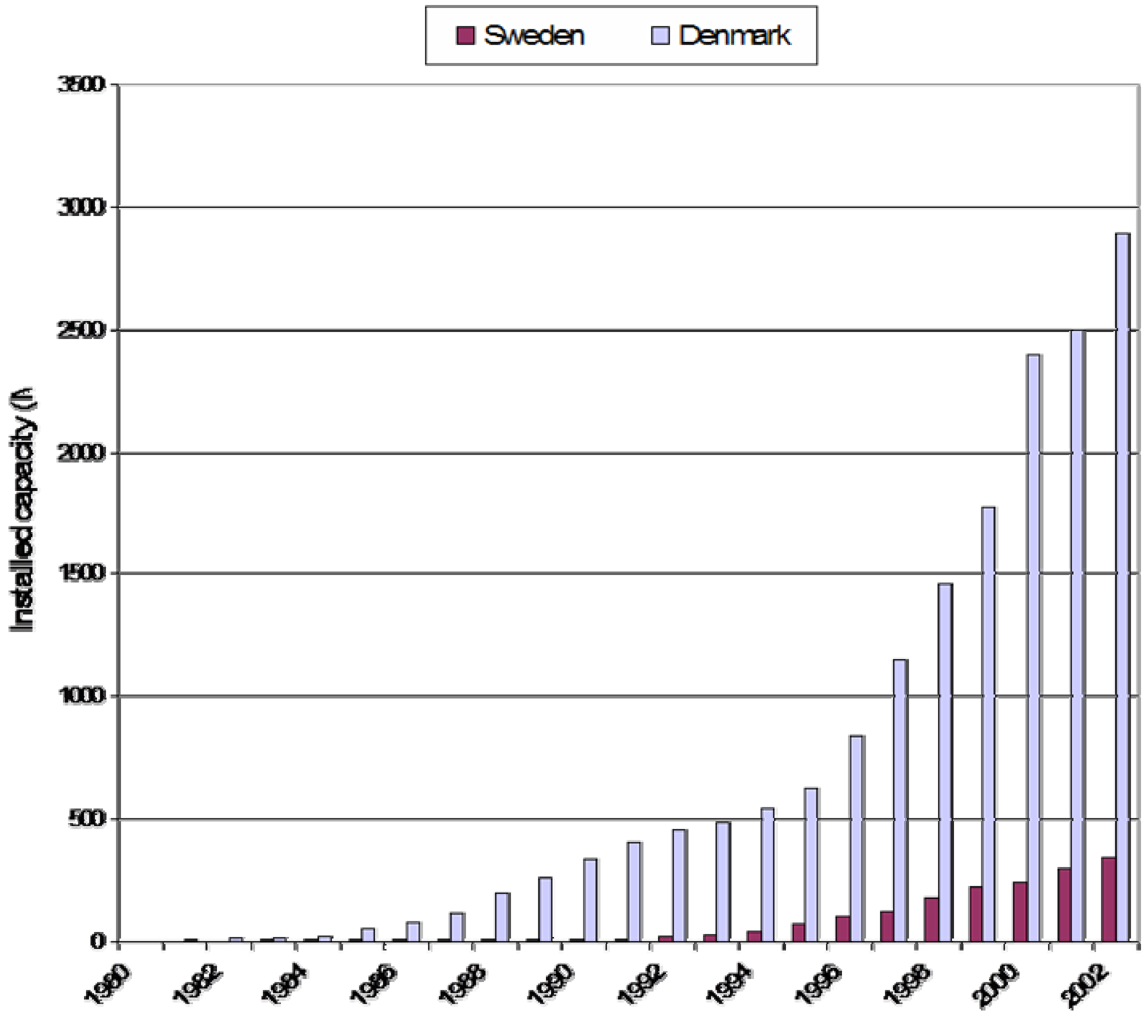


Figure 3. Development of installed wind capacity in Sweden and Denmark from 1975 to 2000 (from Astrand and Neij, 2006).

Economic Support Schemes

In 1991 an investment subsidy of 25 % was introduced which was increased to 35 % in 1993. At the end of the first period of this scheme in 1996 a capacity of 110 MW (350 wind turbines) had been installed.

A second period with an investment subsidy of 15 % was introduced from 1998 to 2002 with the goal of creating an annual increase of 0.5 TWh of wind electricity. In 2002 the installed capacity had increased by 290 MW (374 turbines) and the Swedish government confirmed the same year a goal of a yearly production from wind power of 10 TWh by 2015.

A new support scheme for wind power and other RES was introduced in 2003 based on trading of green certificates. The official goal was to increase the yearly electricity production from RES to 10 TWh in 2010. The first experiences with this scheme, however, did not fulfil the expectations. This has mainly been due to lack of stable and long-range framework conditions for the scheme.

The responsibility of promoting Swedish wind power has been divided between a number of different institutions until 2005 when support for research, development and demonstration was centralized at the Swedish Energy Authority STEM. The support includes a special budget for offshore wind power and for wind power in mountain areas.

A modified certificate trading scheme will be introduced in 2006 in order to accelerate the promotion of electricity based on RES. The new scheme will be running until 2030 and the RES plants are given 15 years contracts for their certificates.

In order to increase the market for trading of green certificates, negotiations between Sweden and Norway concerning a common certificate market have taken place in recent years. The common market was planned to start in January 2007. The new Norwegian government has, however, decided in the spring of 2006 to discontinue these negotiations and to go for another type of support scheme for RES in Norway. This may imply a certain set-back for the Swedish certificate system.

At the end of 2005 the total installed wind capacity in Sweden was about 500 MW and Swedish wind power produced nearly 1 TWh of electricity during 2005 which is less than 1 % of the total electricity consumption. It is estimated by the Swedish government that 4,000 MW of installed wind capacity will be needed in order to fulfil the goal of 10 TWh of electricity from wind by 2015 (Swedish Government Proposition, 2006). The government also proposes that the goal for the total contribution from RES is increased to 17 TWh by 2016 which may require more than 4,000 MW of wind power.

SPANISH WIND ENERGY POLICY

The first state support for wind power in Spain was connected to a law for energy conservation from December 1980. This law regulated the principles for grid connection of wind turbines and introduced an investment support for RES of up to 30%. It also established a tariff for wind electricity to be regulated on an annual basis.

The first grid connected wind farm in Spain consisting of five 120 kW turbines was installed in 1984 by the Spanish utility ENDESA.

A specific plan for the promotion of renewable energy systems in Spain was implemented in 1986. This plan focused on R&D and did not define any national RES targets. It was not until 1991 that such targets were set up in the "Energy Savings and Efficiency Plan 1991-2000" (PAEE) together with earmarked public funding for RES. As a result the total installed wind power capacity in Spain was less than 7 MW by 1990. At the end of 1995 this number had only increased to a little over 100 MW.

However, in the following decade Spain experienced one of the highest growth rates in the world and at the end of 2005 Spain has an installed capacity of over 10,000 MW, only surpassed by Germany. The development of accumulated wind capacity in Spain from 1990 to 2005 is illustrated in Fig. 4.

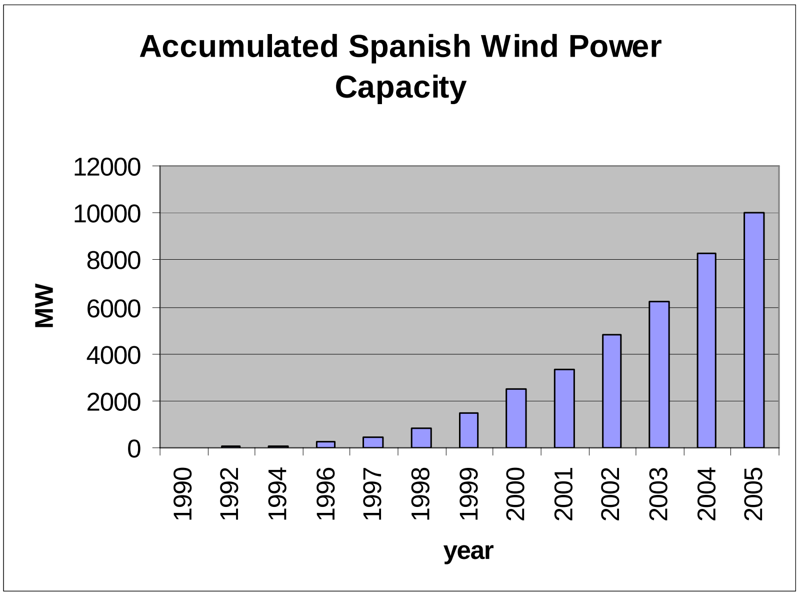


Fig. 4. Development of accumulated wind power capacity in Spain from 1990 to 2005.

Details of the Spanish promotional schemes for wind energy are given by Bechberger (2006). The main points are summarized in the following.

Key Actors in Promotion of Spanish Wind Power

The two main governmental actors in promotion of wind power in Spain have been the *Institute for Energy Diversification and Saving* (IDAE, established in 1984) and the *National Energy Regulatory Authority* (CNE, established in 1998).

IDAE as a governmental agency has had financial autonomy to implement a number of economic support schemes for RES including investment subsidies, soft loans and through capital participation in RES companies. IDAE has prepared the national "1999 Policy Plan for the Promotion of Renewable Energy" (PFER) and an updated version of the plan in 2005 (PER).

The main goal of CNE is to ensure effective competition between energy providers and to protect consumer interests.

In addition, the regional governments of some of the Autonomous Communities (ACs) have played an important role. They have the authority to decide the administrative procedures for RES plants below 50 MW and a number of the ACs have very favourable wind regimes.

The promotion of RES has also been supported by associations representing developers of RES plants. The largest one is the "Association of Renewable Energy Producers" (APPA, established in 1987) which now has about 300 company members. APPA has played an important role through political lobbying and media campaigns for improved economic support for RES.

A special association for the wind energy interests of large corporations was established in 2002 and now operates under the name of "Wind Energy Enterprise Association" (AEE). The second largest Spanish power utility, Iberdrola, has recently invested strongly in wind energy and now owns about 3,000 MW of wind capacity.

Another driving force for wind power has been the Spanish equipment manufactures, where Gamesa Eólica is the most important one with 15 production sites in Spain. In 2004 the company recorded sales of about 1.6 GW of wind power which made it the second largest manufacture of wind turbines on the world market with about 18 % share of installed wind capacity in 2004.

Planning of Wind Power Development in Spain

As mentioned above the first comprehensive energy plan including targets and funding for RES was the PAEE from 1991. The wind target for year 2000 was a total installed capacity of 175 MW. The actual installed capacity by year 2000 turned out to be about 2,500 MW! This may be a world record in underestimation of the possibilities. As the underestimation became obvious during the nineties new and more ambitious plans were set up.

In 1999 the Spanish parliament approved a special "Policy Plan for the Promotion of Renewable Energy" (PFER) with a target which would almost double the share of RES in primary energy consumption from 6.3 % in 1998 to 12 % in 2010. PFER was the first Spanish planning document solely for the promotion of RES. It included technology-specific targets and incentives for the market diffusion of each RES technology, e.g. fiscal instruments as reduction of corporate taxes. For wind energy the target for installed capacity was about 9 GW in 2010 as compared to 835 MW in 1998.

Again the rate of annual wind power installation turned out to be higher than expected and the 2010 target was surpassed already in 2005. At the same time, the total energy consumption in Spain was increasing at a higher rate than expected. As a consequence the wind target for 2010 was updated in September 2002 from 9 GW to 13 GW by 2011.

However, the target increases have not ended by that. At the end of August 2005, the Spanish government has approved a new RES promotion plan named "RES Plan 2005-2010" (PER). According to this plan wind capacity should increase to 20 GW by 2010 corresponding to about a doubling compared to 2005. This target is supported by favourable economic schemes as described in the following. There are interests in the wind power industry to increase this target further, but in order to accept that, the System

Operator will likely demand strong technical requirements for wind turbines in relation to overcoming voltage dips on the grid and to entering into a delegated dispatch center.

Support Schemes for Wind Power

Since 1980, the development of electricity from renewables (RES-E) in Spain has been supported by different schemes including guarantees of grid connection and purchase contracts with utilities at a certain guaranteed price. These concepts were first introduced through the 1980 Energy Conservation Law. The price was not specified in the law but was set annually by Order of the Ministry of Energy and Industry and there was no regulation on the length of contracts. These uncertainties for the investors may be an essential part of the explanation of the slow rate of increase in Spanish wind capacity in the eighties.

A new electricity law was adopted in 1994 (Ley 40/1994) which reduced some of these uncertainties. The new law introduced a minimum period of five years for the purchase contracts and the price were to be set my means of a governmental Royal Decree (2366/1994) which reduces the uncertainty compared to a price set by Ministerial Order. In the period from 1995 -1998 the tariff has been between 6.5 and 6.9 eurocents/kWh.

After the adoption of the EU directive in 1996 on liberalisation of electricity markets new market features were introduced in the Spanish electricity laws. Electricity producers based on RES could choose between three different schemes:

1) The electricity could be sold through a pool system. This was obligatory for all generators with plant capacities above 50 MW. The payment in this system was regulated by the so-called “ordinary regime”.
2) RES generators with plants below 50 MW have a second trade option under the so-called “independent system” where the generators are free to set up bilateral contracts with a distributor, supplier or qualified consumer. However, this system does not offer government guarantees on grid connection, purchase contracts and price.
3) A third trade system is referred to as the “special regime”. This regime guarantees the right to grid connection, a standard five years purchase contract and a defined (revisable) price per delivered kWh. Under the special regime the producers can choose between a “market-based option” and a “revisable tariff option”.

In the market-based option producers are paid the pool price plus an environmental bonus.

A Royal Decree from the end of 1998 (2818/1998) introduced different tariffs and environmental premiums for different green technologies. For wind power the basic tariff has varied between 6.2 and 6.6 eurocents/kWh in the period from 1999 to 2004, while the environmental premium varied between 2.7 and 3.2 eurocents/kWh during the same period.

The combination of favourable feed-in tariffs and the ambitious official goals for the coverage of electricity demand by wind power have given potential investors a high degree of security. This is a significant factor in the high growth rate of Spanish wind capacity from the end of the nineties. The installed wind capacity of about 830 MW by the end of 1998 had grown by nearly a factor of 10 by the end of 2004. By the end of

2005, the installed capacity has exceeded 10,000 MW covering 7.8 % of Spanish electricity demand.

Since 2004 the Spanish energy policy in relation to RES has been increasingly market oriented. This is manifested by a Royal Decree from 2004 (436/2004) by its incentives for RES producers to join the national energy pool. According to this Royal Decree those producers that choose the market option will receive an economic “market bonus” on top of the market price and the green bonus. The green bonus is 40% and the market bonus 10 % of the average consumer price.

The Royal Decree also introduces an element of disincentive in the form of a penalty for missing the announced production by more than 20%. This applies to plants with a capacity above 10 MW. At the end of 2005 about 90 % of the Spanish wind power producers had chosen to join the pool system. This may be explained by the fact that the market bonus is expected to more than compensate for possible penalties. In addition, the high pool price in 2005 has resulted in clearly higher total income per kWh for producers in the market system than for producers with a fixed feed-in tariff.

With increasing penetration of wind power in the Spanish supply system there is a need to include wind power plants in the stabilization of the grid system. New regulations are in preparation which will require wind power plants to ride through abrupt voltage drops in the grid. Another requirement planned for wind power plants larger than 10 MW obliges these plants to join a regional pool of producers which will supply the grid operator with frequent information about the regional wind electricity production. The regional pool administrator shall also inform the grid operator about the regional production prognoses. This is expected to reduce the need for reserve capacity.

A special proposal for support of offshore wind farms has been published in February 2006 based on a tender system. This proposal has been criticised by governmental institutions and organisations of wind producers with reference to less successful experiences in other European countries (e.g. the UK) and to a restrictive cap for the total tariff for the offshore wind farm.

It should be mentioned that a similar tender system has been used in Denmark in 2005 in connection with the 200 MW offshore farm at Horns Reef in the North Sea. But this tender was operating without a cap requirement in contrast to the Spanish proposal.

COMPARISON OF WIND ENERGY DEVELOPMENT IN DENMARK, SWEDEN AND SPAIN

Denmark, Sweden and Spain have had quite different energy policies in relation to wind power. In a short statement Denmark has pioneered the modern phase of wind power based on technological traditions going back to the 1890s, Sweden has only shown a modest interest in wind power until the last few years, while Spain has experienced a slow growth in installed wind capacity until the late nineties where the growth in capacity took off with exceptional high rates. The factors influencing these striking differences are discussed in the following.

Driving Factors in Denmark

In addition to the long historical tradition for wind power in Denmark, the following factors are assumed to have had significant influence on the Danish development in the modern phase of wind power:

- A technological strategy based on a step-by-step increase in turbine capacity starting from the low end (around 20 kW). This permitted a low-cost learning curve in contrast to the case in countries like Sweden and Germany with early emphasis on turbines at MW level.
- Broad public support based on alliances between NGOs and independent energy experts at Danish universities.
- Support in the mid-seventies from official institutions like the Danish Academy of Technical Sciences. This promoted the credibility of wind power resulting in early state support for research, development, demonstration and marketing, especially from the beginning of the eighties.
- Establishment in the late seventies of a test and certification facility at Risø National Laboratories, which included pioneering work on wind atlases.
- Local ownership of turbines, frequently organized in co-operatives. This eliminated most local resistance against wind turbines.
- Establishment of a strong industrial section for production of wind turbines. This started with many small producers in the seventies and eventually stabilized the industrial development with a few large production plants in the nineties.
- Far-sighted official energy plans from the early nineties with emphasis on sustainable energy development and with targets for wind power. Together with favourable economic feed-in schemes this has accelerated the penetration of land-based wind power in the nineties.
- State support for offshore wind power resulted in the world's first large offshore wind farms in the early nineties.

The combination of these driving forces can explain that Denmark in spite of its small population has had a central role for the development of global wind power from the seventies to the end of the century. During this period both the absolute amount of installed wind power capacity and the relatively coverage of national electricity consumption by wind have placed Denmark among the leading countries in the world.

This is changing after the introduction of the liberalised electricity market in the EU and the change of Danish government in 2001. The incoming conservative-liberalistic government has changed the Danish energy policy radically. The development of RES is now mainly left with the commercial market and most of the previous government funding for RES has been abolished. As a result the penetration of wind power in Denmark has stagnated in the last few years.

In 2005 new capacity of only 22 MW was installed, while 18 MW of capacity was taken out of production. This trend has continued during the first three months of 2006 with no new installed capacity and deployment of 1.9 MW of wind capacity.

The ups and downs of Danish wind power development clearly illustrates the central importance of the official national energy policy.

Barriers for wind power in Sweden

In contrast to the Danish case, the Swedish energy policy from the seventies on has focused on development of large turbines at MW scale, and the promotional responsibility was left with the large utilities. Neither of these choices has been favourable to the penetration of wind power in Sweden. The market was not ripe for MW turbines before the end of the nineties and the large utilities were not especially interested in wind power.

The background for the Swedish energy policy may be found in the industrial structure where Sweden, in contrast to Denmark, is characterized by large industrial units producing large scale technologies like cars, airplanes and nuclear plants.

The main factors explaining the relatively slow Swedish implementation of wind power may be summed up as follows:

- Questionable choice of turbine technology from the outset.
- No strong driving forces for wind power.
- No successful national production of wind turbines.
- Bureaucratic procedures for instalment of wind power.
- More focus on biomass than on wind.

Those barriers for the penetration of wind power in Sweden may, however, be reduced by recent initiatives from the Swedish government, including streamlining of the certificate trading system and increased economic support for the promotion of RES. The budget for the Swedish Energy Authority (STEM) has thus been increased by about 80% from 2005 to 2006. STEM also administrates a special budget of about 9 million euros for promotion of offshore wind parks. In addition, the Swedish utility Vattenfall is planning large investments in wind power in the coming years.

Barriers and Driving Forces for Wind Power in Spain

The Spanish energy policy has been characterized by many changes in the support schemes for RES. The resulting uncertainty for investors may be part of the explanation for the late take-off of Spanish wind power. Other factors are needed, however, in order to explain the exceptional high growth in installed capacity since the late nineties. The following summary is an attempt to explain this special development:

- Short-range and varying support schemes have created uncertainties for potential investors and have delayed the exploitation of Spanish wind potential until the late nineties.
- There were no significant national production of wind turbines in Spain until the late nineties. This was changed especially by Spanish Gamesa Eólica which is now one of the largest turbine producers in the world.

Gamesa now covers the whole chain including manufacturing of turbines, ownership and operation of wind farms and trading in the pool.

- The favourable Spanish feed-in system introduced in the late nineties has given strong incentives for potential investors and developers.
- A number of the governments of Autonomous Communities have supported the implementation of wind power.
- One of the largest Spanish utilities, Iberdrola, has invested heavily in wind power and has a close co-operation with Gamesa Eólica.
- The increasing electricity consumption in Spain has made more room for wind power than e.g. in Denmark and Sweden with less growth in electricity demand. As a consequence Spanish utilities have been less sceptical concerning the penetration of wind power.
- The increasing dependence on imported fuels and problems with fulfilling the Kyoto commitments have prompted the Spanish government to promote renewables and especially wind power.

CONCLUSIONS

Although Denmark, Sweden and Spain all have good wind power potentials, the exploitation and development of this potential have been quite different in the three countries. One important factor in this connection is the official energy policy of the country involved. This is clearly illustrated by the Danish development where a recent shift in government and energy policy has discontinued the successful penetration of wind power in Denmark. Reference to a possible saturation of acceptable land based sites in Denmark can only partly explain the stagnation of Danish wind power.

Concern about global warming, an approaching oil peak and energy supply security in general has prompted many European governments and a number of European utilities to give high priority to renewables and especially wind. As an example, recent Danish utility scenarios support a coverage of electricity demand by wind of up to 50 % before the middle of this century. This will require new system thinking where wind turbines actively support the overall system balance and are able to ride through voltage drops in the grid and other irregularities. The development of such wind power technologies is presently taking place and demonstration on large scale systems should be supported by governments.

ACKNOWLEDGEMENTS

Thanks are due to support from the DESIRE project sponsored by the EU Commission. Special thanks are due to Dr. Carlos Madina for personal information in relation to the Spanish energy development.

REFERENCES

Bechberger M. 2006. Why renewables are not enough: Spain's discrepancy between renewables growth and energy (in)efficiency. Forthcoming in: Lutz Mez (ed.) Green Power Markets: Case Studies and Perspectives. Multi-Science Publishing. Brentwood, UK.

Beuse E, Boldt J, Maegaard P, Meyer NI, Windeleff J and Østergaard I. 2000. Renewable Energy in Denmark – History of 25 Years of Growth 1975 to 2000 (in Danish). OVE Publishers. Aarhus, Denmark.

Blegaa S, Hvelplund F, Jensen J, Josephsen L, Linderoth H, Meyer NI, Balling N. and Sørensen B. 1976. Sketch of Alternative Danish Energy Plan (in Danish). OVE Publishers. Copenhagen, Denmark.

Blegaa S, Josephsen L, Meyer NI and Sørensen B. 1977. Alternative Danish Energy Planning. *Energy Policy*: 87-94.

Damborg S. 2003. Public Attitudes Towards Wind Power (in Danish). Danish Wind Industry Association. www.windpower.dk

Danish Academy of Technical Sciences. 1975. Wind Power (in Danish). Copenhagen. Denmark.

Danish Academy of Technical Sciences. 1976. Wind Power 2 – Proposal for an Action Programme (in Danish). Copenhagen. Denmark.

Danish Energy Authority. 1986. Large Windmills in Denmark. Copenhagen, Denmark.
Danish Energy Authority. 2001. Status of Green Certificate Market Development. Copenhagen, Denmark.

Danish Ministry of Economy and Trade. 2003. Announcement on Law Concerning Electricity Supply. Law No. 151, March 10, 2003. Copenhagen, Denmark.

Danish Ministry of Energy.1981. Energy Plan 81. Copenhagen, Denmark.

Danish Ministry of Energy. 1990. Energy 2000 – A Plan of Action for Sustainable Development. Copenhagen, Denmark.

Danish Ministry of Environment and Energy. 1996. Energy 21 – The Danish Government's Action Plan for Energy. Copenhagen. Denmark.

Danish Ministry of Industry and Commerce. 1976. Danish Energy Policy 1976 (in Danish), Copenhagen, Denmark.

Danish Wind Industry Association. 1993. Attitudes on Wind Power (in Danish). Ringkøbing, Denmark.

European Communities. 1997. Directive 96/92/EC of the European Parliament and of the Council of 19. December 1996 conerning common rules for the internal market in electricity. *Official Journal of the European Communities.* January 30.

Grubb MJ and Meyer NI. 1993. Wind Energy: Resources, Systems, and Regional Strategies. In *Renewable Energy: Sources for Fuels and Electricity,* edited by T.B. Johansson, H. Kelly, A.K.N Reddy and R.H. Williams. Washington D.C. Island Press: 157-212.

Hvelplund F, Illum K, Meyer NI, Nørgård JS and Sørensen B. 1983. Energy for the Future (in Danish). Borgen Publishers. Copenhagen, Denmark.

Lund P, Cherian S and Ackermann T. A Cell Controller for Autonomous Operation of a 60 kV Distribution Area. 2006. *International Journal of Distributed Energy Resources* 2: 83-100.

Meyer NI and Koefoed AL. 2003. Danish Energy Reform: Policy Implications for Renewables. *Energy Policy* 31: 597-607.

Meyer NI. 1995. Danish Wind Power Development. *Energy for Sustainable Development* 2: 18-25.

Petersen EL, Troen I, Frandsen S and Hedegaard K. 1981. Wind Atlas for Denmark. Risø National Laboratory. Roskilde, Denmark.

Swedish Government Proposition. 2006. Environmental Benign Electricity with Wind Power – Means for a Sustainable Wind Energy System (in Swedish), Proposition 2005/06:143. Stockholm, Sweden.

Åstrand K and Neij L. 2006. An assessment of governmental wind power programmes in Sweden – using a systems approach. *Energy Policy* 34: 277-296.

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Poul Alberg Østergaard, Aalborg University, Denmark
E-mail	poul@plan.aau.dk
Title of dissemination	Cogeneration of power & heat and cogeneration of power and desalinated water; modelling for optimal system performance
Type of activity	Presentation at conference Article in conference proceedings
Title of forum	PowerGEN Middle East 2007
Language	English
Date of dissemination	22 January 2007
Place of dissemination	Manama, Bahrain
Brief abstract / description of dissemination activity	Cogeneration of heat & power and cogeneration of desalinated water and power have similarities from an energy systems perspective. Both introduce limitations in the freedom of action but also introduce possibilities for integrating fluctuating renewable energy sources. Through energy systems analyses, it was demonstrated how storage tanks desalinated water could introduce a buffer corresponding to heat storages for optimising performance of energy systems with respect to integrating fluctuating energy sources.
Audience impact assessment	POWERGEN Middle East is the largest series of power conferences and trade shows in the Middle East with a high attendance. The idea that CPH plants can be used to integrate fluctuating power sources is a novel idea in the Middle East and did generated some interest in the audience causing feed back after the conference session
Dissemination	Included after this form

Renewable energy as a means for climate change mitigation in interconnected transmission grids

Dr Poul Alberg Østergaard

Aalborg University

Denmark

Abstract

Due to readily available and largely inexpensive oil resources, the exploitation of renewable energy resources in the Middle East is largely confined to some solar thermal exploits and 108 MW of wind power mainly in Egypt. Meanwhile electricity consumptions are increasing in the region while at the same time, on the global political agenda, climate change mitigation is gaining momentum particularly after the EU environmental ministers in March 2005 agreed on setting stronger carbon dioxide emission reduction targets.

At modest penetration wind power merely substitutes electricity generated typically at thermal power plants and thereby only giving economic benefits comparable to the saved marginal fuel and O&M costs. At higher penetrations, it becomes increasingly important for the energy system to be able to operate without costly reserve capacity awaiting fluctuations in demand or wind power generation that need be countered.

The Middle East is not generally bestowed with good wind energy resources, however some areas have reasonable resources and future prospects of photo-voltaic cell-based electricity

generation are favourable. Furthermore, transmission grids are only in the process of becoming interconnected in the region. This interconnection is mainly in order to assist in reducing reserve capacity in the existing thermal power generation systems. While indeed relevant in thermal systems, however, this is typically even more so in renewable energy based systems, where fluctuations to a large extent are uncontrollable making interconnected systems prerequisites for proper integration of electricity produced on such energy sources.

Using a European example this article demonstrates how different demand and production patterns in different geographical areas assist in evening out fluctuations and imbalances between demands and productions in systems with high penetrations of renewable energy thereby reducing needs for reserve capacity. Prospects that will also be relevant for the Middle East with interconnected power grids if renewables are to play a large role in this region.

Introduction

The transition from fossil fuel-based power generation to power generation based on fluctuating energy sources such as wind, sun, and wave power introduces challenging demands on the operation of electricity systems. Even without such constraints, other constraints in the form of cogeneration of power and heat, the cogeneration of power and cooling or the cogeneration of power and desalinated water impose problems on the system's load-following capability. Development in the way electricity is being consumed adds another dimension to the issue. Traditional electric engines decrease their power up-take if generators are overloaded thus causing the frequency to drop and thereby relieving the generators of some load. With many electric engines operated through frequency-converters, loads are not relieved but rather kept constant.

The Middle East is only exploiting renewable energy resources to a very modest degree, so any possible problems in load-balancing in the current situation are mainly attributable to the other factors listed. Adding simplicity but thereby also disusing potentials for load balancing is the lack of a transmission grid between Middle Eastern countries or even a lack inside the individual countries.

With the ongoing interconnection project, (The Gulf Electricity Interconnection Grid), a shift has been set in motion regarding changing the electricity from being national or even local affairs to being a regional affair, the latter factor is under change. Through the Gulf Electricity Interconnection Grid, the members of the Cooperation Council for the Arab States of the Gulf will eventually connect to the Mediterranean Middle East and Europe through Turkey as well as through the Arab-Maghreb line to North Africa and Spain. Though such distances are beyond what is readily technically feasible in terms of power exchange it does emphasize the interconnection trend of the larger area.

While the Gulf Electricity Interconnection Grid primarily is in order to reduce reserve capacity requirements as discussed by e.g. Bowen et al. (2002) and illustrated by the interconnection costs being distributed proportional to the individual countries reserve capacity savings, it will also have a positive effect on the exploitation of renewable energy sources. Apart from most notably electricity production based on solid renewable fuels and hydropower, most renewable energy sources are characterised by intermittent natures and therefore an inherent need of either reserve capacity or other means of dealing with the fluctuations. In general, the smaller the system, the fewer the plants, the smaller the variation in energy sources and the smaller the geographic extension of the area in question, the larger the need for reserve capacity.

In line with the European Union’s adoption of a stringent Kyoto-derived carbon dioxide emission reduction target, Denmark has pursued an ambitious energy policy. This has resulted in a complex energy system with many sources of energy being tapped and many interdependencies between sources, demands and conversion systems. In addition, however, Western Denmark has 1200 MW AC capacity to Germany, 1100 MW HVDC capacity to Norway and 700 MW HVDC capacity to Sweden while Eastern Denmark has a total capacity of 1900 MW to Sweden and 600 MW to Germany. Though not mutually connected (see figure 1), the two non-synchronised areas of Denmark thus each have strong ties abroad aiding in power balancing and reducing needs for reserve capacity. The Western Danish connection are summarized in table 1.

Country	Capacity	Type of connection
Germany	1200 MW	Multiple AC lines (400, 220 & 150 kV)
Sweden	600 MW	Underwater HVDC line
Norway	1100 MW	Underwater HVDC line

Table 1: Summary of foreign electric connections from Western Denmark.

Figure 1: The 400 kV transmission grid in Denmark and connections abroad. Western Denmark is AC connected to Germany while Eastern Denmark is AC connected to Sweden and the two areas are not synchronized.

In addition to the issue of mere generating capacity, an added issue is that of ancillary services which is getting increasing attention within utilities and the research community addressing the integration of fluctuating electricity sources. This is increasingly important as these have traditionally been supplied by the large power plants and with stronger reliance on distributed generation technologies or international connections, the systems must maintain resilience against grid disturbances without resorting to the ancillary service providers of the past.

Scope of article

The scope of this article is to analyse how much back-up capacity is required in the Western Danish electricity system in the balancing of this system. The analyses are made under different assumptions regarding the supply of ancillary services, under different assumptions regarding the variation curves of supply and demand as a consequence of areas being interconnected or not and under different assumptions of developments in installed wind power capacity; wind power being he most notable fluctuating power source in Denmark.

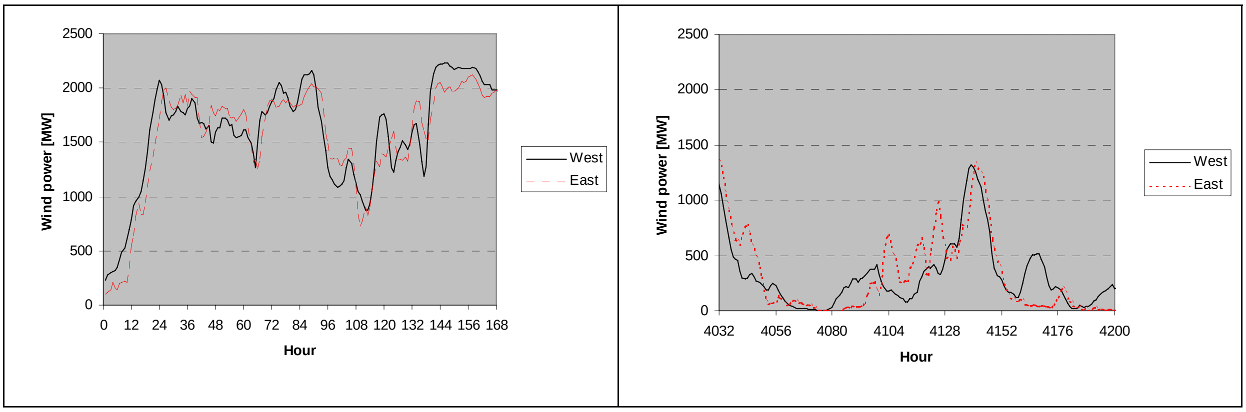
Time variations of demands and productions

Both production and consumption varies in a diurnal cycle, a weekly cycle and a seasonal cycle. The diurnal cycle of the demand is due to the timing of meal preparation, industrial activity, need for illumination etc. The weekly demand cycle due to the reduced needs of weekend-closed companies, institutions and organisations and the seasonal demand cycle due to changing needs for illumination, heating and cooling.

The production system has to follow the demand variations, so the production should equal the demand curve neglecting international trade. In addition however, in systems exploiting renewable energy sources or cogeneration of heat or cooling and power (CHCP), additional time variations are introduced. The CHCP plant will have a production which is determined by temperature variations which vary in a daily and a seasonal cycle as well as with a stochastic element. The same applies to photo voltaic-based electricity generation where the altitude of the sun varies with the yearly cycle on top of which comes local climatic conditions influencing cloud coverage. The last to be mentioned here is wind power, which probably has the widest addressed fluctuations in power output of any generating technology. Depending on geographical setting, wind power may have a diurnal variation with a tendency of lower production at night than during the day as is the case in Denmark and a seasonal variation with generally higher wind velocities during the winter at the same time as the density of the air is higher thus adding to the power.

All these are factors contributing to the difficulty of designing energy systems with load following capabilities. One factor works against these fluctuations of which some are long-term foreseeable, some are short-term foreseeable and some are not foreseeable: geographic distribution of the production and the demand.

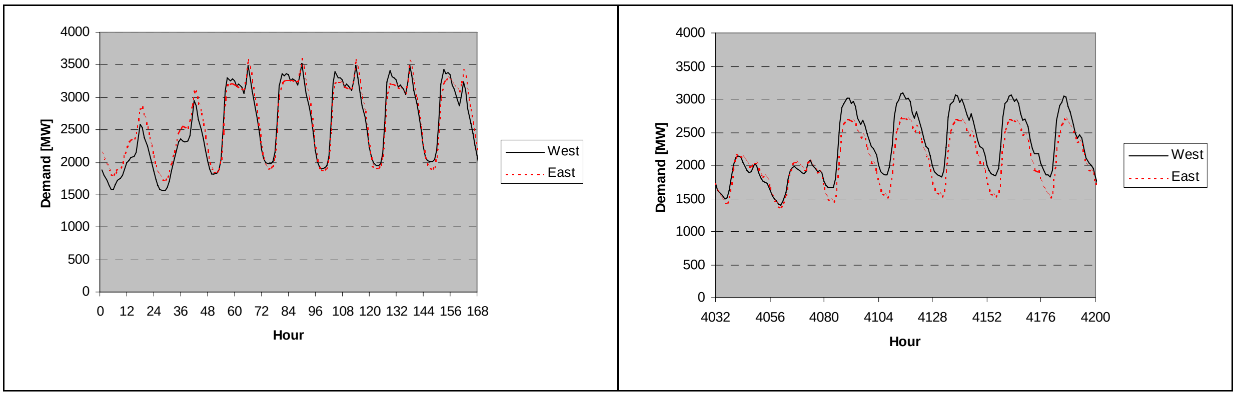
In figures 2 and 3 for instance, hourly wind power inputs for the two non-connected areas of Denmark are shown for a winter and a summer week respectively.



Figures 2 & 3: Wind power generation in Eastern and Western Denmark a winter and a summer week in 2005 respectively. Values for Eastern Denmark have been scaled so the half-year average matches that of Western Denmark. Sources: Eltra (2005) and Elkraft System (2005).

The two individual areas variations are higher than for the two areas combined. For the entire year 2004 for instance, wind input in Western Denmark averaged 555 MW and in Eastern Denmark 195 MW. The average deviation from these averages were 411 and 148 MW respectively indicating the fluctuating nature of wind power. Scaling Eastern Denmark to the Western Danish average the 148 MW would correspond to 411 MW. However, adjoining the two areas and again scaling to the Western Danish average, the average deviation would fall to 400 MW. This is of course not sufficient to render a flat production curve but is does demonstrate how enclosing a larger geographic area adds stability to the production. Particularly when taking into account the relatively modest size of Denmark and the derived situation that the country is usually subjected to the same depressions and high pressures.

Demands in the two parts of Denmark are relatively similar though with a tendency of a lower demand in the Eastern part during the summer as indicated in figures 4 and 5. In order to gain an improved – i.e. more even – diurnal demand curve, larger geographic areas would need be covered. Areas encompassing areas or countries with diverse industrial bases with different mixtures of primary, secondary and tertiary economic sectors would even out demand peaks caused by large single users or clusters of similar and often partly synchronized industries. If it is habitual that certain types of industries work the same shifts in a country, then this aggravates the peaks. Covering more time zones in a demand area will also generate a natural alleviation of larges power surges.



Figures 4 & 5: Electricity demand in Eastern and Western Denmark a winter and a summer week in 2005 respectively. Values for Eastern Denmark have been scaled so the half-year average matches that of Western Denmark. Sources: Eltra (2005) and Elkraft System (2005).

This is of course from an overall system perspective. Technical, economic or organizational bottlenecks may influence the extent to which the effects of geographic dispersion may be utilised.

Energy system scenario

The analyses in this article take their point of departure in an energy system scenario for the year 2020 used in analyses by the Danish Energy Authority (DEA (2001a+b)). Demands are thus the expected with a continuation of present trends and policies. The amount of on-shore and off-shore wind corresponds to the present level although particularly off-shore wind is expected to increase in the future. Going even beyond the current level of approximately 20% wind share in Western Denmark, however would limit the extent to which the analyses and results would be relevant and valid in other countries.

Thermal power plants are modelled as two types; CHP plants supplying electricity to the grid as well as heat to district heating areas and plants operating in condensing mode i.e. only with electricity generation. These latter are merely modelled present in adequate quantities.

Finally, a certain degree of heat humps are include to assist integration of the fluctuating wind resource.

Consumption [TWh]	Generating capacity [MW]	
24.87 Electricity	2750	Cogeneration of heat and power (CHP)
20.00 District heat	5000	Central stations – Condensing operation
	2400	Wind (inland and off-shore)
	350	Heat pumps

Table 1: Energy system scenario parameters.

The core point of the analyses is of course to model the impact of adjoining areas and benefiting from the equalization of diurnal, weekly and seasonal variation curves. However due to a lack of available data, this is limited to the two areas of Denmark that are well-described in terms of publicly available data. As noted regarding figures 4 and 5 however, demand variations are not so large, so mainly the impact of the wind variations are modelled here. This is done by comparing the energy system response to

A) applying the actual wind generation of a year on an hourly basis with
B) applying an artificial wind generation of a year on an hourly basis averaging the actual data from the two areas where the smaller Eastern Area is weighed to match the Western level.

In one analysis, however, demand is modelled applying an artificial demand curve averaging the actual demand curve and the same curve shifted six hours as an indication of the response of the system to a drastic geographic equalisation.

The main analyses are furthermore conducted with two different regulation strategies in which the local CHP plants are operated 1) according to a heat demand and 2) to best help keep overall electricity load balance while also furnishing the required heat.

In order to model the response of systems without the Danish heat-tied production and thus in order to obtain results valid for other climates, the system is then modelled in a situation with and in a situation without the CHP-tied heat demand that is applicable mainly in temperate and cold climates.

Finally, the system is modelled with higher quantities of wind power correspond to levels twice and three times the present level.

The energy system is modelled using the EnergyPLAN model developed by Henrik Lund (Lund et al (2004)) which is a model designed to make analyses of energy systems with high degrees of fluctuating power and heat sources and many interdependencies of the energy systems. The parameter used for assessing the energy system performance is the required level of electricity generation in condensing mode operation as this has the lowest overall thermodynamic efficiency and therefore should be avoided. These are the back-up plants and is the load than can be relieved through interconnection.

Results of energy systems analyses

Modelling the energy system reveals that average production on condensation based power plants is decreasing slightly using the artificial wind distribution compared to using the actual wind distribution. This applies to Regulation Strategy 1 and 2 as well as for the situation without any heat demand and CHP generation as indicated in figure 6. In fact, however, as it also evident from the results in figure 6, differences are small and change over the year.

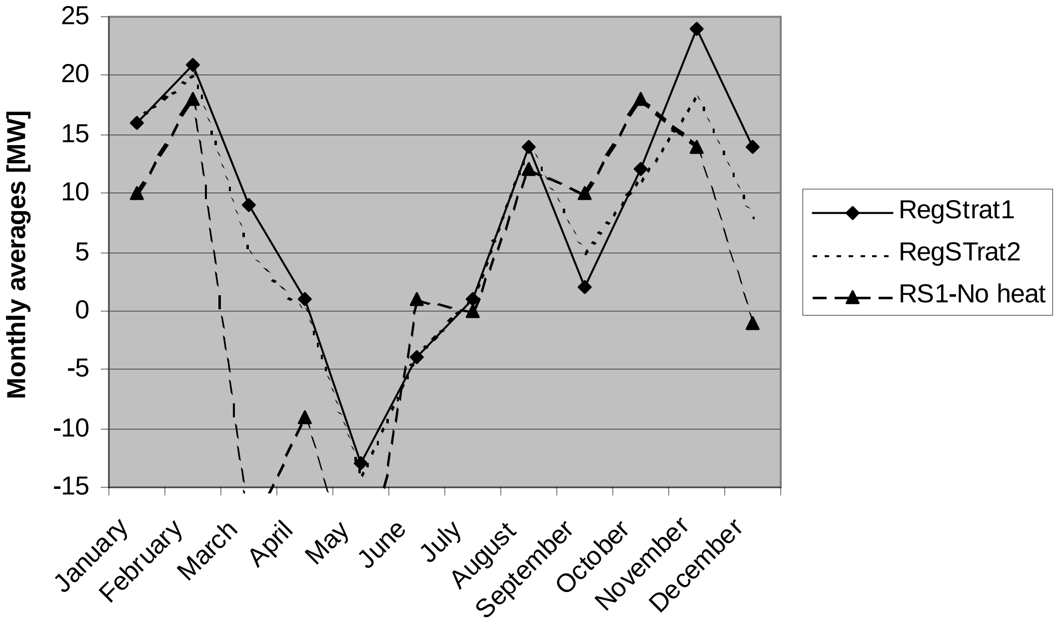


Figure 6: Change in average monthly condensation-based power generation with the artificial yearly wind distribution curve with Regulation Strategies 1 and 2 and in a situation without any heat demand covered by CHP. Positive values indicate reduced condensation-

based power generation compared to the reference scenario with the actual wind distribution.

In some cases - times with negative values in the graphs - the actual wind distribution curve proves better than artificial and equalized wind distribution curve. For the entire year, average condensation-based power generation does nottheless decrease by 7-8 MW by adopting the more levelled wind power distribution curve. Although limited, it does indicate prospects particularly taking into consideration that the marginal electricity production typically is at older and less fuel-efficient plants.

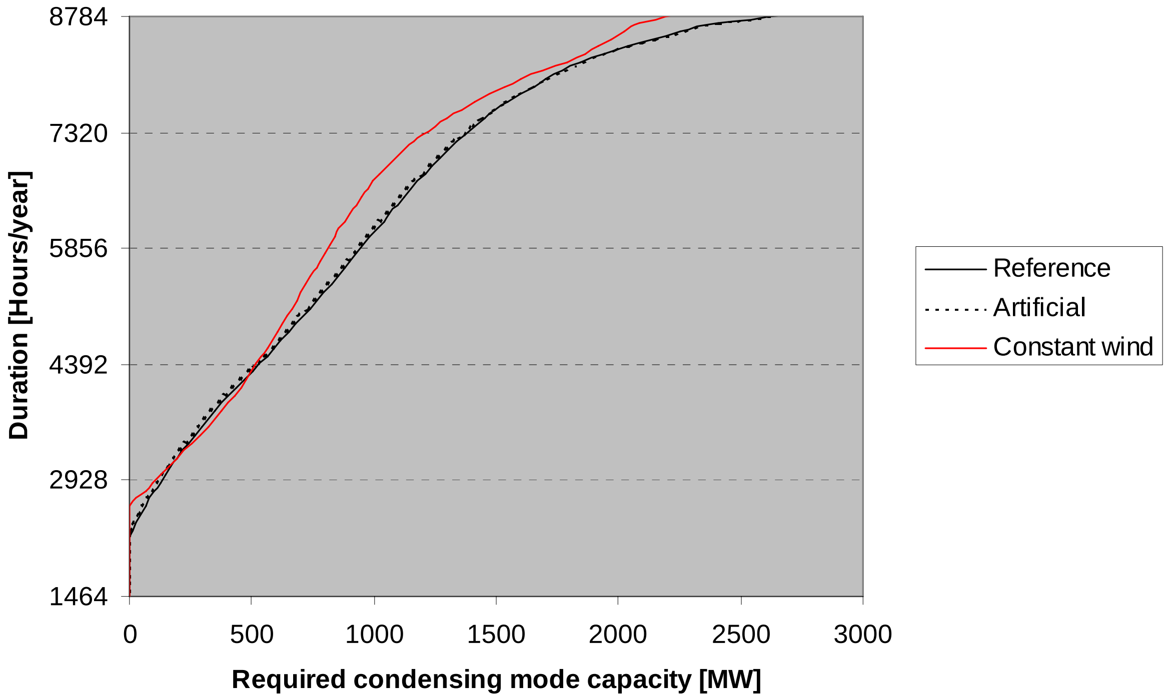


Figure 7: Duration curve for the reference system and for system with artificial annual variation curve for wind power and a system with constant wind power of 550 MW throughout the year.

Showing the results in the form of a duration curve for condensation-based power generation as in figure 7 demonstrates the same marginal shift to the left from applying the constructed wind distribution curve for a larger geographic area. It also shows the duration curve in case wind power gave a fixed input corresponding to evening out wind variation over a very large area. Even in this case, condensation-based power generation would increase at points as was also evident from figure 6. The reason of course being that with stochastic wind power, wind variations will follow demand at times.

Without heat demand tying CHP production and thus electricity generation, condensing mode electricity generation naturally increases as shown in figure 8, and with the levelled variation curve of wind power applied, demands are marginally lower

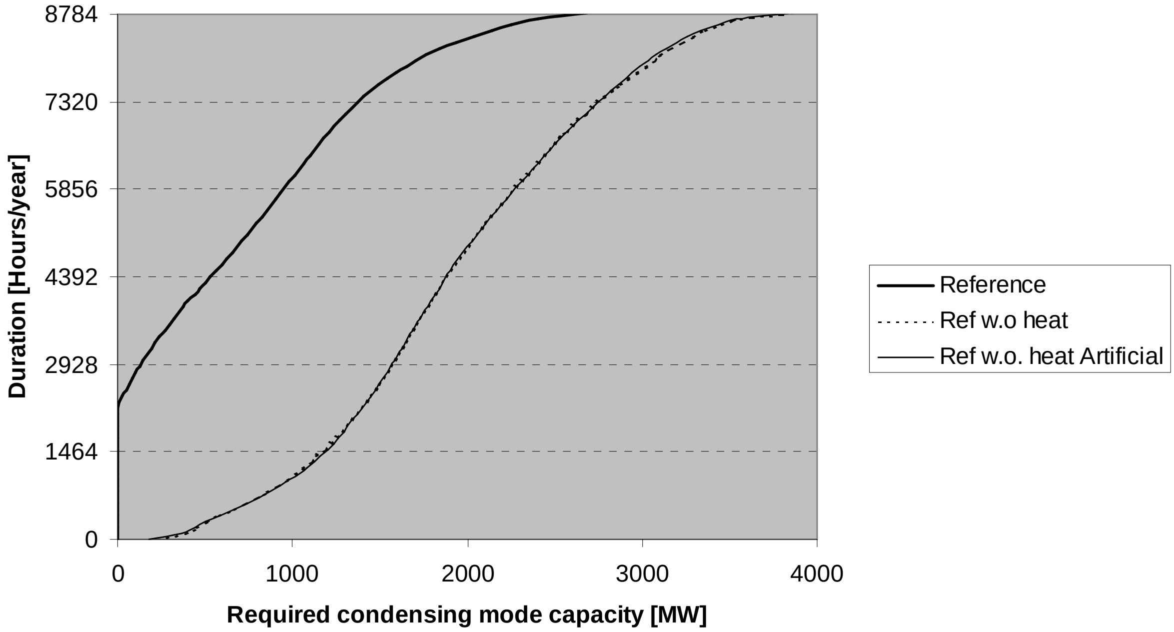


Figure 8: Duration curve for the reference system and for system without heat demand and thus heat-tied CHP generation with 2004 annual wind variation curve and artificial annual variation curve for wind power.

These results are natural as wind power at its present level of approximately 20% of the demand only constitute a modest share. Not in terms of share relative to the shares of wind power based generation in other countries but modest compared to the thermal generation either being in the form of power plants operating in condensing mode to supply solely electricity or CHP plants supplying both heat and electricity to consumers.

Assuming a higher penetration of wind power, results with the actual wind distribution and with the constructed artificial wind distribution diverge more as illustrated in figure 9 showing results for the energy system assuming double and triple the amount of wind power presently available. Here applying the more level wind distribution curve reduces correspondingly higher shares of electricity generation in condensing mode operation.

One apparent element in figure 9 deserving a comment is the fact that high wind (as illustrated by the triple curve) may require a higher level of electricity in condensing mode operation. This is due the present circumstance that wind turbines do no actively assist in maintaining grid stability – i.e. frequency stability, voltage stability and in supplying adequate short-circuit power available. At high levels of instantaneous wind production, thermal power plants – CHP plants or condensing mode plants need to generate a correspondingly higher output to supply the required ancillary services.

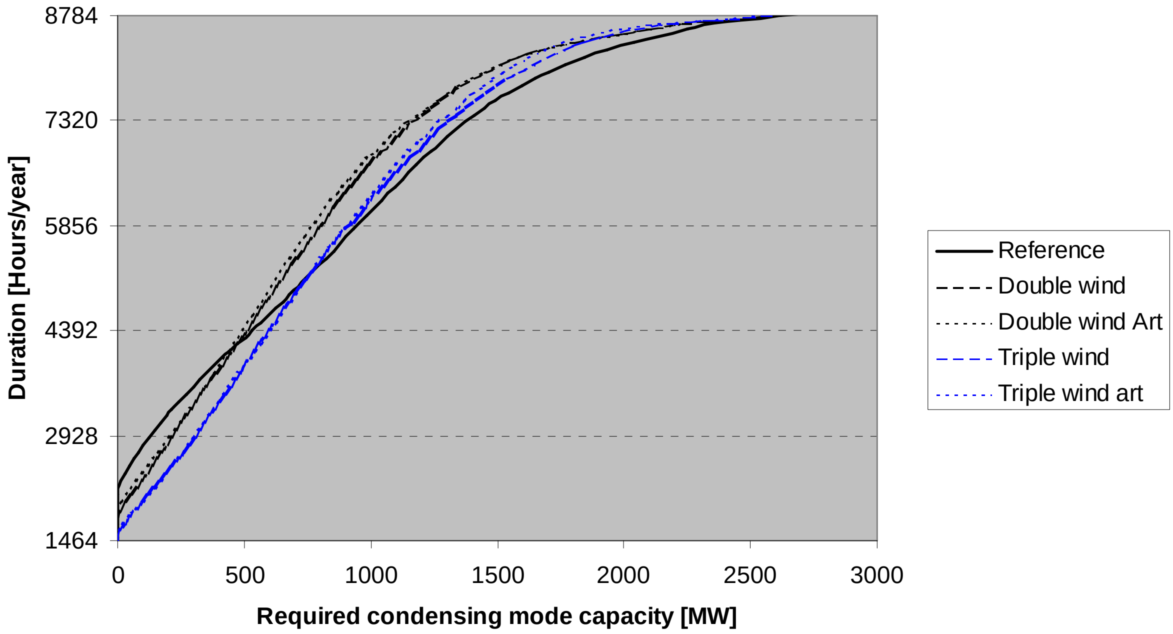


Figure 9: Duration curve for the reference system and for system with double and triple the amount of wind power with 2004 and artificial annual wind variation curves for wind power.

If ancillary services were supplied from wind turbines, the duration curves in figure 9 would shift to the left and have a more gentle inclination.

Conclusions

The results of this paper demonstrate that increasing the geographical extension of the area in which renewable fluctuating energy sources are being exploited reduces the need for stand-by capacity in the form of power plants operating in condensing mode operation. While the analyses have focused on one single source of renewable energy i.e. wind power, the analyses indicate that analyses of energy systems encompassing more unrelated energy sources or areas with larger geographic distributions would lower the demand for stand-by capacity further. This is thus also the result of interconnecting transmission areas with distinct production or consumption patterns.

In terms of integrating renewable energy sources, the result also demonstrate that while it is important encompassing a large area to obtain a stabile production, concern for ancillary services must be a priority as this can otherwise impede transition to renewable energy sources if conventional thermal power plants need to supply these.

Fulfilment of Kyoto-requirements living up to similar standards is thus more easily accomplished in an economically sound fashion in interconnected systems.

Sources

Bowen et al. (2002) *Policy analysis in the development of integrated Middle East regional energy markets*, Brian H. Bowen, F.T Sparrow, Zuwei Yu and Muhammed Al-Salamah in Proceedings of 8th International Power Generation Conference, Dubai, October 7-9, 2002

DEA (2001a): Report from the workgroup on electricity production form CHP and RES, Danish Energy Agency, Copenhagen 2001 (In Danish)

DEA (2001b): Attachments to report from the workgroup on electricity production form CHP and RES, Attachment 6. Danish Energy Agency, 2001. (In Danish)

Elkraft Transmission (2004): Årsrapport 2004 [Annual report 2004]. Elkraft Transmission 2004.

Eltra 2005: Online production and demand database available at www.eltra.dk

Elkraft System 2005: Online production and demand database available at www.elkraft-system.dk

Lund et al 2004: *EnergyPlan – Computer model for energy system analyses Version 6.0*, Henrik Lund, Ebbe Münster & Leif Holm Tambjerg, Aalborg University 2004

UAE Interact (2005) *GCC power grid contract to be awarded soon*, UAE Interact – The Official Website for the Ministry of Information and Culture in the UAE, March 22nd 2005 http://uaeinteract.com/news/default.asp?ID=314

Dissemination strategy on Electricity balancing

DESIRE

large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Anders N. Andersen, EMD International A/S Henrik Lund, Aalborg University
E-mail	ana@emd.dk
Title of dissemination	New CHP Partnerships offering balancing of fluctuating Renewable Electricity Productions
Type of activity	Article in peer-reviewed journal
Title of forum	Journal of Cleaner Production, 15 (2007), pp. 288-293
Language	English
Date of dissemination	2007
Place of dissemination	Worldwide
Brief abstract / description of dissemination activity	The paper present solutions, which will integrate fluctuating renewable electricity supplies such as wind power into electricity systems using small and medium seized Combined Heat and Power plants (CHP). Such solutions calls for new organisational setup for partnerships and software tools to be used by partnerships of small and medium seized CHP, enabling them e.g. to combine and act as ‘virtual big power plants’.
Audience impact assessment	The article is directed at the international research society and is expected to have a large impact on the development of new strategies in the energy field.
Dissemination	Included after this form.

Available online at www.sciencedirect.com
ScienceDirect
Journal of Cleaner Production 15 (2007) 288–293
Journal of Cleaner Production
www.elsevier.com/locate/jclepro

New CHP partnerships offering balancing of fluctuating renewable electricity productions

Anders N. Andersen [a], Henrik Lund [b,*]

[a] EMD International A/S, Niels Jernes Vej 10, 9220 Aalborg, Denmark
[b] Department of Development and Planning, Aalborg University, Fibigerstraede 13, 9220 Aalborg, Denmark

Received 8 July 2005; accepted 10 August 2005
Available online 5 April 2006

Abstract

Combined heat and power (CHP) as well as intermittent renewable energy sources (RES) are key elements in future cleaner electricity production systems. This article presents solutions which will integrate fluctuating renewable electricity supplies, such as wind power, into electricity systems using small and medium-sized combined heat and power plants (CHP). Such solutions call for a new organisational setup of partnerships and software tools. The software tools will allow the new partnerships to offer services which are currently only offered by big power plants to electricity markets. The article presents recent results of the development and implementation of such partnerships and focuses on the methodologies and computer tools necessary in order to allow the partnerships to optimise their behaviour on the market. The use of such tools and methodologies makes groups of small CHP plants able to replace large power stations and, at the same time, allows for the integration of a higher share of RES in the electricity supply, resulting in a decrease in both fossil fuels and CO2 emissions.

Keywords: Sustainable energy systems; CHP; Power system modelling; Renewable energy; District heating; Electricity markets; Energy management; Spot market; Regulating power market

1. Introduction

European Energy Policies have given priority to the problem of global warming. Both energy efficiency and the development of new and renewable energy technologies are considered key elements of the solution of this problem. Thus, the replacement of boilers and power stations with CHP units and the integration of an increased share of RES in the energy supply are solutions presented by the European Union. At present, the EU objectives are to increase the share of RES in electricity production from 14% to 22% and the share of CHP from 9% to 18% by year 2010. Small CHP plants play an important role in the achievement of such objectives and their potential has been investigated and discussed in several member countries [1–6].

The implementation of such policies results in an increased share of distributed generation. The generation shares of some areas and regions are likely to be much higher than the average share. The objective of increasing the average share of RES electricity production to 22% is distributed on the EU member states and this results in RES percentages between 6 and 78%. Meanwhile, large-scale integration of RES and distributed generation raises the problem of creating a balance between electricity demand and production. The EU targets for the deployment of CHP and renewable energy will only be achieved if this balance can be created in most, if not all, EU member states, and in the EU accession states. Furthermore, the distribution of renewable sources raises the problem of transmission capacities between different regions on the European electricity grid, which has to be addressed too. Also in this context, the balancing within regions is of significant importance [7–11].

If this integration of renewable electricity is not achieved, it will have a negative effect on the electricity trade across the borders of the EU member states. Proportions of renewable

* Corresponding author. Tel.: +45 9635 8309; fax: +45 9815 3788.
E-mail address: lund@plan.aau.dk (H. Lund).

0959-6526/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jclepro.2005.08.017

electricity rise and electricity inter-connectors with limited capacities are blocked up by the need to transport excess renewable electricity supplies. This is a problem which is already affecting Denmark and Germany, since large excess of wind power are often produced in Jutland and Schleswig Holstein.

2. CHP partnerships

CHP is a very efficient way of transforming fuels into energy services. A number of studies have investigated the methodologies of optimising different CHP technologies in relation to variations in the district heating demand and energy conservation of buildings [12–18]. Such studies have also included the development of models to optimise the use of heat storage capacities into the operation [19,20].

Compared to the conventional approach of producing heat and power in separate plants, CHP plants have the potential of decreasing fuel consumption by 20–30%, while producing exactly the same amount of electricity and heat. Meanwhile, such increase in efficiency can only be achieved when electricity and heat are produced simultaneously at the same location. Consequently, CHP has mainly been used in connection with district heating supply of large urban areas and typically in large steam turbines using fossil fuels. Small CHP plants offer the possibility of distributed generation and thus, give two obvious advantages. First, the CHP efficiency can be used also in small urban areas and industries. Secondly, local biomass resources can replace fossil fuels and ashes can be recycled without major transportation costs [21–23].

The Danish Energy Policy has succeeded in stabilising primary energy supply during a period of 30 years of economic growth. Small CHP plants and different types of renewable energy have been introduced and supported by the government [24–28], and one of the most important successes has been to decrease the fuel consumption for heating in households by 30% in the period from 1972 to 1996. During the same period of time, a 90% oil-based primary energy supply in 1972 has been replaced by a mixture of oil, coal, natural gas, and renewable energy [29].

The success can be explained by the combination of energy conservation mainly achieved by insulation, and the expansion of district heating based on CHP. Insulation of houses has resulted in a 12% decrease in the heat demand from 1972 to 1996, at the same time as heated areas have increased by 46%. In the same period, district heating was expanded by more than 50%, and in general, CHP plants have replaced boilers. Consequently, fuel consumption for heating per square metre decreased by 53% from 1972 to 1996. Approximately 40% of this decrease is caused by energy conservation, while the rest is due to the expansion of CHP.

Initially, CHP in Denmark was expanded in city areas, where power stations were already located. Secondly, during the 1990s, CHP plants were built in towns and even villages. Today, more than 50% of the electricity demand is produced on CHP plants, many of which are small CHP plants. The small Danish CHP plants are typically built in connection with district heating systems in towns and villages. The CHP plants contain one or more CHP units, peak load boilers and heat storage. The CHP units are either engines, gas turbines, or in some cases steam turbines or combined cycle plants.

The CHP plants already have considerable experience in optimising their electricity production against the triple tariff which has existed for almost 10 years. Consequently, the CHP plants know how to organise the production of the CHP units in order to optimise their profit [30]. Meanwhile, Denmark is in the process of replacing such pricing conditions by spot market prices. Consequently, new methodologies and tools for the optimisation of the daily operation of small CHP plants are needed. The new markets include regulating power which meets short-term imbalances and supplies ancillary markets concerned with improving frequency and voltage control. Meanwhile, bidding on the Regulating Power Market requires a minimum capacity of 10 MW. Since many small CHP plants are not able to meet the demanded minimum they need to enter into CHP partnerships in order to be able to benefit from the new opportunities. Moreover, small CHP plants may benefit from the involvement in public-private partnerships in order to finance long-term contracts and gain low interest loans for renewable energy generation [31].

3. Methodology of partnership bidding

When a CHP plant only sells electricity on the spot market, it does not need to join a partnership with other CHP plants. However, it does need tools for the optimisation of its daily operation. The biddings on the Nord Pool spot market for each hour of the following day must be given no later than at 12 a.m. the day before. Subsequently and no later than at 3 p.m., Nord Pool informs all bidders of the result. This means that from 3 p.m., the CHP plant has complete knowledge of how to organise its production until the end of the following day.

A simple example of the bidding strategy on the spot market is shown in Fig. 1. In this example, a CHP plant has only one CHP unit. The strategy is to make the CHP unit produce when the prices on the spot market are expected to be high and in similar manner, to stop the engine when the prices are expected to be low. The figure consists of three curves.

The upper curve shows the expected variations of the spot market electricity prices during one week, and it shows the bidding price at which electricity is offered on the spot market from this CHP unit. In this example, the bidding price on the spot market is equal to the price at which the CHP unit can produce heat at the boiler. The spot prices are expected to be high during daytime hours and low during night hours. The next curve shows the hours when the production from the CHP is planned to be offered. The bottom curve gives the expected content of thermal energy in the heat storage. The content increases when the engine is running and decreases when it is stopped. Thus, the storage is used to make it possible for the engine to produce in the best-paid periods.

When a CHP plant plans to increase its income on the regulating power market, it needs to establish a partnership with

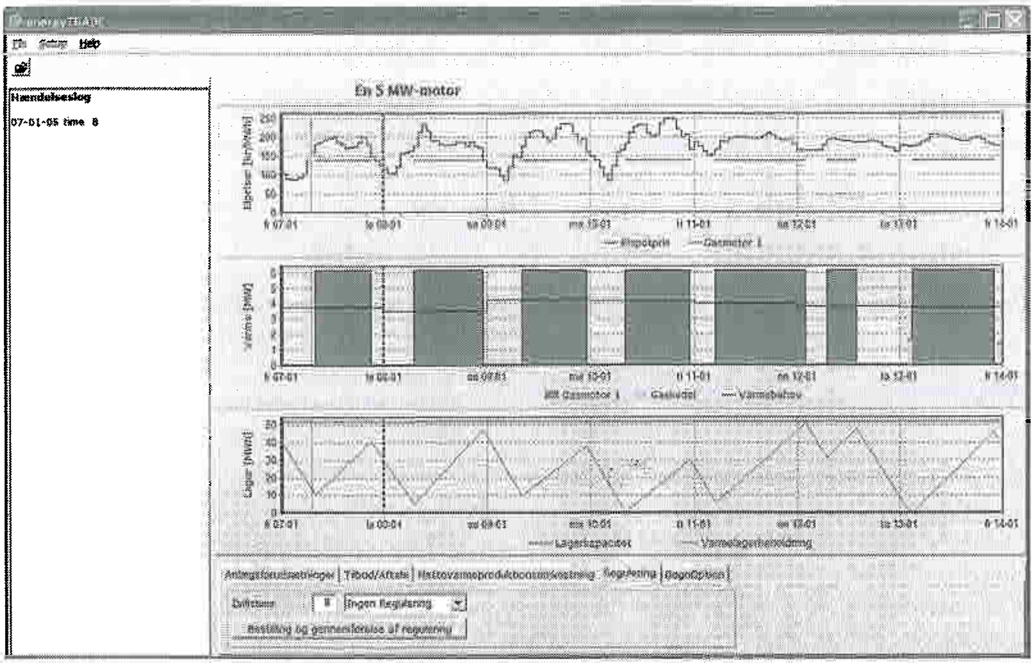


Fig. 1. Bidding strategy on the spot market for a CHP plant with one 5 MW gas engine.

other CHP plants in order to do so. One reason is that the bidding on the regulating power market requires a minimum of 10 MW. Another reason is that it is an extremely fast market place. After having won a regulation on the regulating power market, the CHP units which won the regulation only has 15 min to change their production. This calls for an IT solution, which enables the partnership to start and stop the CHP units at the participating plants. A third reason is that the modification of the bidding strategy on the spot market also enables the CHP plants to earn money on the regulating power market. If the partnership, for example, consists of 10 CHP plants, each of them having two 2 MW CHP units (in total 40 MW), the modified bidding strategy on the spot market could be to win the production on at least five CHP units (in total 10 MW) at each hour and at each hour not to offer production on at least five CHP units (in total 10 MW). This would enable the partnership to offer both a *downward* regulation and an *upward* regulation at each hour.

Thirty minutes before the hour at which a *downward* regulation and an *upward* regulation are offered, the bidding prices for regulation are to be sent to the Transmission System Operator (TSO). The bidding prices for each of the CHP units of the partnership have to be carefully calculated. In order to achieve a better understanding of the calculation principle of the bidding prices, the following should be noted.

The upward regulation of a CHP unit at a CHP plant at a certain hour has the consequence that sooner or later during the following week, the heat production from a CHP unit or a boiler must be correspondingly decreased. Thus, the upward regulation typically involves an increase in the fuel consumption at the hour followed by a subsequent decrease. Furthermore, it may also involve the loss of opportunities to sell electricity on the spot market at certain hours.

Finally, the operator of the CHP plant needs to make sure that an upward regulation of a certain CHP unit does not prevent the CHP plant from fulfilling electricity productions on the spot market, where contracts have already been signed. Consequently, the operator must know whether or not an upward regulation at the hour to come will lead to a situation in which the heat storage becomes full and thereby prevents the CHP units from producing more heat. In such case, the operator cannot make an upward regulation bid for this specific CHP unit.

The same set of considerations applies for the downward regulation. A downward regulation of a CHP unit at a CHP plant at a certain hour has the consequence that sooner or later during the following week, the heat production from a CHP unit or boiler must be correspondingly increased. Thus, the downward regulation involves a decrease in the fuel consumption at the hour followed by a subsequent increase. Furthermore, it may also involve the opportunities to sell extra electricity on the spot market at certain hours. The operator of the CHP plant does *not* need to make sure that a downward regulation of a certain CHP unit prevents the CHP plant from fulfilling the electricity productions on the spot marked which have already been agreed upon. The only negative consequence of winning downward regulations is the fact that it will later be necessary to start economically less attractive boilers.

Based on the above considerations, the calculation of the bidding prices *for each CHP unit at each CHP plant* can be determined by following these four steps:

Step 1: It has to be determined whether an upward regulation can be done without hindering the spot market productions already contractually entered. In such case, no biddings are to be given. The number of hourly contracts already made depends on the time of the day. Until 12 a.m., only productions during the present day have been agreed upon. From 12 a.m., offered productions until the end of next day have to be taken into account.

Step 2: It has to be determined whether the additional heat production from the CHP unit as a consequence of an upward regulation leads to either a decrease in the boiler production or a reduced production to the spot market. In the first case, the upward regulation bidding price becomes equal to the spot market bidding price of the hour. In the latter case, the regulation price is equal to the spot price of the hour at which the CHP plant cannot produce to the spot market. Such price has to be found partly on the basis of the expectations to the future price. Typically, the price is higher than the price of the present hour

Step 3: Similar to the upward regulation, it has to be determined whether the missing heat production from a downward regulation has to come from a boiler or from a CHP unit at a later time. In the latter case, the consequence is the possibility of producing and selling more electricity on the spot market. Again, in the first case the bidding price becomes equal to the spot market bidding price of the hour. In the latter case, it is equal to the price of the hour at which the CHP plant can increase productions on the spot market. Typically, the price is now lower than the price of the present hour.

Step 4: It has to be determined whether the expected number of starts and stops of the CHP unit changes in the coming week due to a potential upward or downward regulation, and such costs are included in the calculation. Typically, the start of a gas engine costs approximately 60 DDK (equal to 8 euros) per MW capacity.

4. Results and examples of bidding price calculations

The above-mentioned principles of calculating upward and downward bidding prices for the regulating power market have been implemented in the computer tool energyTRADE, which will be used in the EU-funded DESIRE project (Dissemination strategy on Electricity balancing for large Scale Integration of Renewable Energy). By use of this tool, an analysis of bidding prices at the 5 MW CHP plant is shown, as illustrated in Fig. 1, where a vertical dotted line shows the agreements of spot market productions made until the end of day one.

In the example, we begin by looking at hour number 8 (indicated in Fig. 1 by a vertical line). This hour is especially attractive for an upward regulation, because it enables the CHP unit to continue with the productions won on the spot market without introducing an extra start. The bidding price at hour 8 is found by placing the production quantity at hour 8 and then recalculating how this production is expected to change the productions of the coming week. The change in net production costs for the coming week (production costs subtracted the value of sold electricity) is converted to a bidding price. In this case, energyTRADE calculates the change in costs of upward regulation to be 196 DKK/MWh. The market price ended at 272 DKK/MWh and the CHP plant won the regulation job.

In the next example, the downward regulation bidding price at hour 12 is calculated. Again, the energyTRADE model changes the production at the hour and recalculates how this missing production is expected to change the productions of the coming week (see Fig. 2). In this case, the price is influenced by the fact that the downward regulation involves an additional stop and start of the engine and the bidding price is calculated to 118 DDK/MWh.

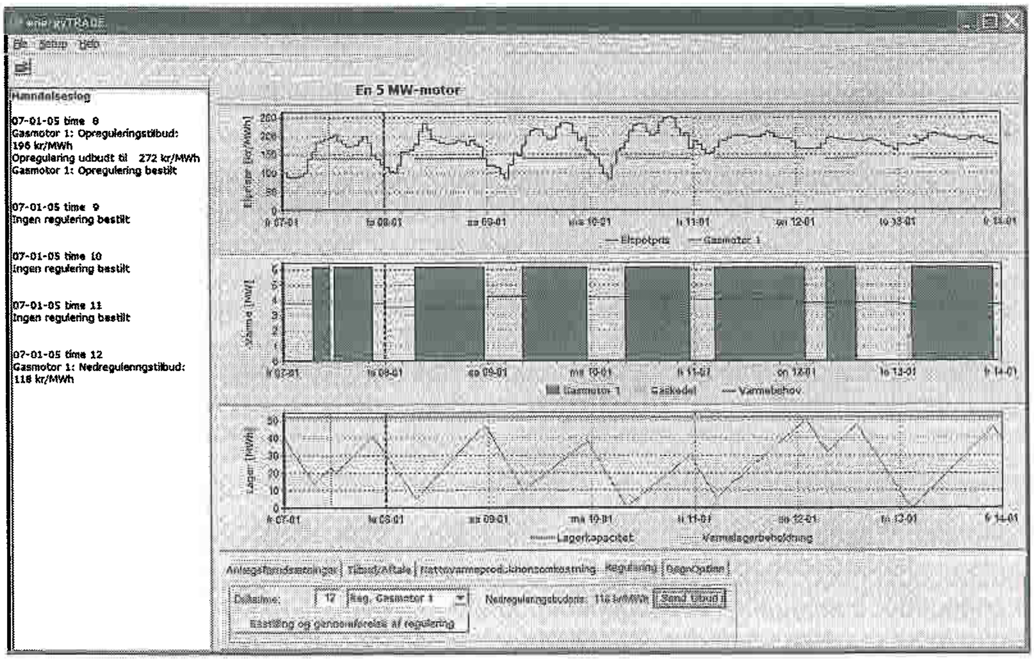


Fig. 2. An energyTRADE calculation of a downward regulation bidding price at hour 12. The production at hour 12 is removed and then it is recalculated how this missing production at hour 12 is expected to change the productions of the coming week.

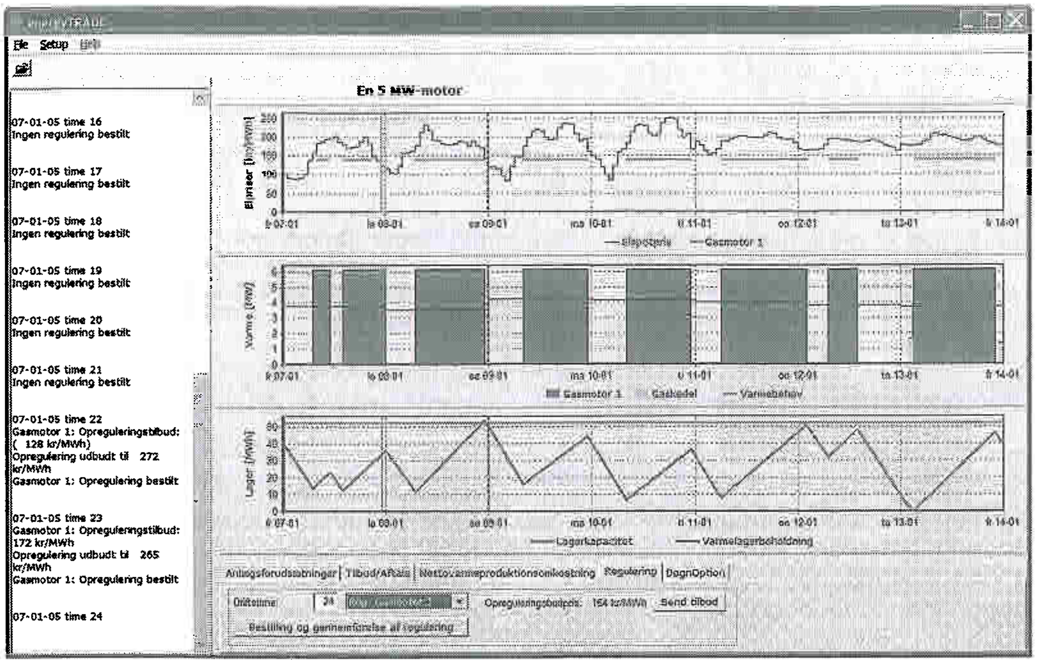


Fig. 3. Bidding on an upward regulation at hour 24 is not possible because of overfilled heat storage the following day.

In this case, we assume that the CHP plant wins downward regulation at hours 12, 13 and 14. Now, the next step is to calculate the upward regulation bidding prices at hours 22, 23 and 24 (see Fig. 3). At hours 22 and 23, regulations are possible, prices can be calculated and upward regulation is won in this case. Meanwhile, upward regulation at hour 24 is not possible, because it would prevent the CHP plant from fulfilling electricity productions the following day when contracts have already been made on the spot marked (in Fig. 3 this can be seen as an overfilled heat storage the following day).

The example illustrates why both upward and downward bidding prices will vary substantially. Table 1 shows the results in the example.

5. Conclusions

Both CHP and renewable energy are important parts of the European climate change policies. The introduction of CHP plants into the electricity market can help along the integration of fluctuating electricity productions for renewable energy sources. Such solutions call for a new organisational setup for partnerships and software tools to be used by small and medium-sized CHP plants, enabling them to co-operate and act as 'virtual big power plants'. This article presented the principle methodologies and tools of calculating such partnership bidding prices for the regulating power market. This will allow the new partnerships to offer services which are currently only offered by big power plants to electricity markets.

Table 1
Resulting bidding prices in the example

Operation hour	Regulating power offer	Bidding price (DKK/MWh)
8	Upward	196
…	…	…
…	…	…
12	Downward	118
13	Downward	172
14	Downward	131
…	…	…
…	…	…
22	Upward	128
23	Upward	172
24	NOT possible	!!!!

Acknowledgements

The article is part of the EU-funded DESIRE project (Dissemination strategy on Electricity balancing for large Scale Integration of Renewable Energy). The DESIRE project represents an example of the importance of making partnerships for sustainable development and for inventing new efficient energy products and technologies.

References

[1] Toke D. Policy network creation: the case of energy efficiency. Public Administration 2000;78(4):835–54.
[2] Hvelplund F, Lund H. Rebuilding without restructuring the energy system in east Germany. Energy Policy 1998;26(7):535–46.
[3] Lund H, Hvelplund F, Kass I, Dukalskis E, Blumberga D. District heating and market economy in Latvia. Energy 1999;24(7):549–59.
[4] Lund H, Hvelplund F, Ingermann K, Kask U. Estonian energy system – proposals for the implementation of a cogeneration strategy. Energy Policy 2000;28(10):729–36.
[5] Möller B. Geographically determined interactions of distributed generation, consumption and the transmission network in the case of Denmark. In: Proceedings of the second international symposium on distributed generation, October 2–4, Stockholm; 2002.

[6] Rasmussen LH. A sustainable energy-system in Latvia. Applied Energy 2003;76(1–3):1–8.
[7] Alberg Ostergaard P. Transmission-grid requirements with scattered and fluctuating renewable electricity-sources. Applied Energy 2003; 76(1–3):247–55.
[8] Clark W, Isherwood W. Distributed generation: remote power systems with advanced storage technologies. Energy Policy 2004;32(14): 1573–89.
[9] Lund H, Ostergaard PA. Electric grid and heat planning scenarios with centralised and distributed sources of conventional, CHP and wind generation. Energy 2000;25(4):299–312.
[10] Lund H, Clark WW. Management of fluctuations in wind power and CHP comparing two possible Danish strategies. Energy 2002;27(5):471–83.
[11] Ostergaard PA. Modelling grid losses and the geographic distribution of electricity generation. Renewable Energy 2005;30(7):977–87.
[12] Bhatt MS. Mapping of general combined heat and power systems. Energy Conversion and Management 2001;42(1):115–24.
[13] Blok K, Turkenburg WC. CO_2 emission reduction by means of industrial CHP in the Netherlands. Energy Conversion and Management 1994; 35(4):317–40.
[14] Dotzauer E. Simple model for prediction of loads in district-heating systems. Applied Energy 2002;73(3–4):277–84.
[15] Khan KH, Rasul MG, Khan MMK. Energy conservation in buildings: cogeneration and cogeneration coupled with thermal energy storage. Applied Energy 2004;77(1):15–34.
[16] Larsen HV, Bohm B, Wigbels M. A comparison of aggregated models for simulation and operational optimisation of district heating networks. Energy Conversion and Management 2004;45(7–8):1119–39.
[17] Rolfsman B. Optimal supply and demand investments in municipal energy systems. Energy Conversion and Management 2004;45(4):595–611.
[18] Yilmaz T. Optimization of cogeneration systems under alternative performance criteria. Energy Conversion and Management 2004;45(6): 939–45.
[19] Gustafsson SI, Karlsson BG. Heat accumulators in CHP networks. Energy Conversion and Management 1992;33(12):1051–61.
[20] Palsson OP, Ravn HF. Stochastic heat storage problem – solved by the progressive hedging algorithm. Energy Conversion and Management 1994;35(12):1157–71.
[21] Maeng H, Lund H, Hvelplund F. Biogas plants in Denmark: technological and economic developments. Applied Energy 1999;64(1–4): 195–206.
[22] Murphy JD, McKeogh E, Kiely G. Technical/economic/environmental analysis of biogas utilisation. Applied Energy 2004;77(4):407–27.
[23] Sipila K, Solantausta Y, Kurkela E. Long-term cogeneration and biomass strategies for reducing CO_2 emissions in Finland. Energy Conversion and Management 1993;34(9–11):1051–8.
[24] Arler F. Global partnership, climate change and complex equality. Environmental Values 2001;10(3):301–29.
[25] Christensen P, Lund H. Conflicting views of sustainability: the case of wind power and nature conservation in Denmark. European Environment 1998:81–6.
[26] Clark WW, Jensen JD. The role of government in privatization: an economic model from Denmark. International Journal of Technology Management 2001;21(5–6):540–55.
[27] Meyer NI. European schemes for promoting renewables in liberalised markets. Energy Policy 2003;31(7):665–76.
[28] Remmen A. Greening of Danish industry – changes in concepts and policies. Technology Analysis & Strategic Management 2001;13(1):53–69.
[29] Lund H. Choice awareness: the development of technological and institutional choice in the public debate of Danish energy planning. Journal of Environmental Policy & Planning 2000:2249–59.
[30] Lund H, Andersen AN. Optimal designs of small CHP plants in a market with fluctuating electricity prices. Energy Conversion and Management 2005;46(6):893–904.
[31] Clark WW, Lund H. Civic markets: the case of the California energy crisis. International Journal of Global Energy Issues 2001;16(4):328–44.

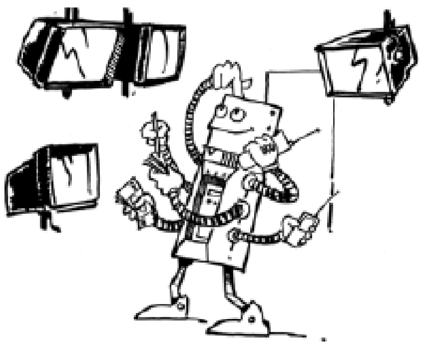
Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Ebbe Münster, PlanEnergi, Denmark
E-mail	em@planenergi.dk
Title of dissemination	Energy Trader
Type of activity	Writing of paper for the Committee of Energy Policy in the Danish Parliament
Title of forum	Meeting in the Committee of Energy Policy in the Danish Parliament, March 29th, 2006
Language	Danish
Date of dissemination	March 3rd, 2006
Place of dissemination	Ea Energianalyse, Copenhagen.
Brief abstract / description of dissemination activity	Based on the findings of the Energy Camp 2005 an idea for a system for optimal operation of household appliances, the Energy Trader, was developed. The core of the idea is to make information on online energy prices (eventually prognoses for prices) available for a central unit in the house. This unit is also able to communicate with all relevant appliances including heating elements via Bluetooth or similar wireless protocols. If mass production could bring the price for such systems down to less than say 1000 € they might be commercially relevant and have important positive effects on the DSM capacity of the entire distribution system. The idea need political support because it relies on the necessary standards for communication to be decided.
Audience impact assessment	Some members of the committee understood the importance of this idea and promised to work for the realisation.
Dissemination	Included after this form

I anledning af Folketingets Energipolitiske Udvalgs møde om Energy Camp, 29. marts 2006.

Energy Trader

1. Sammenfatning: Energipolitisk Udvalg kan fremme et mere intelligent energiforbrug
På Energy Camp 05 blev ideen om Energy Trader udviklet. Energy Trader er et koncept, som skal give husholdninger billigere opfyldelse af deres energitjenester ved at tilpasse energiforbruget til varierende energipriser.



Dagens energisystem er i høj grad udviklet i en tid hvor kommunikation og regnekraft ikke er hvad den er i dag. Der er store gevinster at høste ved at udnytte disse nye muligheder. Et mere intelligent energisystem vil kunne bane vejen for mere vindkraft og vil kunne give et billigere og mere sikkert energisystem. Samtidig vil synliggøre af elforbrug og behovsstyring give direkte elbesparelser.

Energipolitikkerne kan fremme denne udvikling ved en række tiltag:

- Der bør udarbejdes en politik for udbredelse af fjernaflæste energimålere. Dette kan omfatte krav om at alle nye målere skal kunne håndtere timemåling og en tidshorisont for en total fornyelse af målerne. Dette vil være i tråd med EU's kommende energiservice-direktiv. Erfaring fra lignende forløb kan hentes fra Italien, Sverige, Storbritannien og Australien.
- Der bør igangsættes udviklingsprojekter for en hensigtsmæssig udformning af dynamiske tariffer for fjernvarme og for el-distributionsselskaber. De nuværende tariffer er udviklet i en tid uden intelligente målere og giver ikke et omkostningsægte prissignal.
- De bør igangsættes aktiviteter med det formål at sikre åbne kommunikationsstandarder i forbindelse med home automation. Sådanne åbne standarder er en forudsætning for at der kan etableres et egentligt marked for udstyr der kan overvåge, måle og styre energiforbrug efter brugernes behov og efter aktuelle energipriser.
- Kommunikationen til husets udstyr bør *ikke* ske via energimåleren, men derimod via Internettet. En binding til energimåleren vil give et uoverskueligt antal systemer og protokoller. Brug af Internettet kan blive plug-and-play og kan give en fri konkurrence mellem alternative leverandører af home automation.
- De nuværende elafgifter modvirker den intelligente energianvendelse. Den ens beskatning i alle årets timer forvrider de bagvedliggende priser. Energiafgiften (som primært betales af husholdningerne) kunne målrettes så den i højere grad beskattede det miljøbelastende, det dyre og der hvor konkurrencen er mindst: Nemlig elforbruget i dagtimerne.

Energy Camp kan ses som energibranchens forsøg på nytænkning. Vi tror på at et koncept som Energy Trader, kan realiseres. Men det kræver nytænkning – også hos politikkerne.

2. Energy Trader – ønske om et mere intelligent energisystem

På Energy Camp 05 blev ideen om Energy Trader udviklet. Energy Trader er et koncept, som skal give husholdninger billigere opfyldelse af deres energitjenester ved at tilpasse energiforbruget til varierende energipriser. Synliggørelse af energiforbrug for hele bygningen og de enkelte apparater vil samtidig skabe grobund for energibesparelser, styring af forbrug efter faktisk behov samt ud fra aktuelle og forventede energipriser.

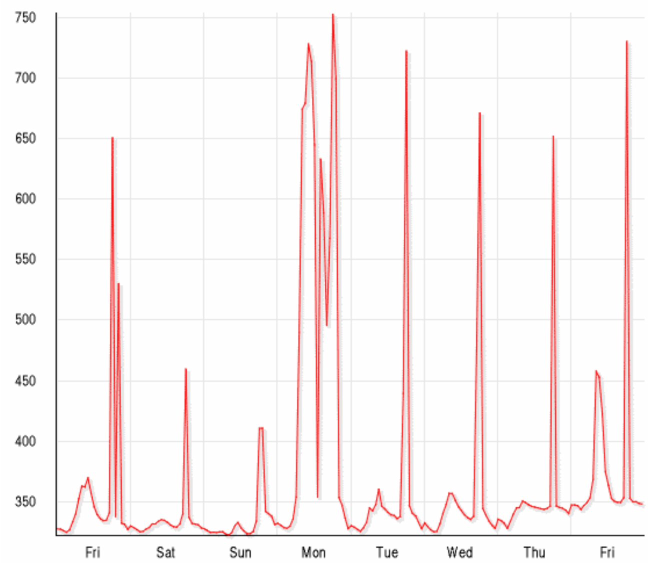
I beskrivelsen af Energy Trader lægges vægt på at det skal være let at anvende og ekstremt fleksibelt. Grundidéen er at det er forbrugeren der bestemmer og agerer ud fra den aktuelle markedssituation. Dette vil være en markant ændring til dagens situation, hvor hele systemreguleringen er fokuseret på produktionssiden med samlede udgifter omkring ¾ mia. kroner. Energiselskabet sender prissignaler og hver enkel familie indstiller automatikken, så deres præferencer er i højsæde.

En mulighed for at udvikle et økonomisk attraktivt system er at funktionen med at overvåge, måle og styre energiforbruget også udnyttes til andre formål. Der kan høstes synergi med områder, som fx energibesparelser, bedre komfort, overvågning (indbrud, brud på ledninger), fjernstyring og underholdning.

Hvad er prisfølsomt energiforbrug?
Figuren til højre viser spotpriserne for Østdanmark i ugen frem til 3 marts 2006[1]. Hver dag er der prisspidser, hvor prisen er det dobbelte af normalt.

Prisfølsomt energiforbrug betyder ganske enkelt at de dyre timer undgås.

Ser man på den sidste prisspids så har den en varighed på 1 time. Fra 17-18 er prisen 35 øre/kWh, fra 18-19: 73 øre/kWh og fra 20-21: 35 øre/kWh. Man kan således halvere omkostningen ved at forsinke forbruget i 1 time.



Et andet eksempel er den 28. november, hvor der i Østdanmark var rekordhøje priser kl 17-18 på 13,46 kr./kWh. Sådanne ekstreme udsving kan blive mere almindelige i fremtiden.

Hvorfor er det vigtigt?
For den enkelte familie kan der spares penge ved en intelligent styring, og der kan være sideeffekter i form af bedre sikkerhed m.m.

For samfundet er et prisfølsomt elforbrug en forudsætning for at forsyningssikkerheden skal kunne opretholdes i det liberaliserede elmarked. Forbruget bliver nødt til at være ”det yderste kraftværk”. Det er ikke realistisk at kommercielle producenter vil investere i et kraftværk, som kun benyttes nogle få timer om året. Til få driftstimer (op til 100-400 timer per år) er forbruget overlegent –

[1] Figurens y-akse er i kr/MWh. 10 kr/MWh = 1 øre/kWh. Nord Pool, 3. marts 2006.

moderne kommunikationsteknologi kan erstatte traditionelle værker[2]. Overfor disse muligheder står, som allerede nævnt, at dagens tilpasning mellem efterspørgsel og produktion i dag alene sker på produktionssiden med store udgifter til følge.

Vindmøller og decentral produktion (også nye former som mikrokraftvarme, solceller, brændselsceller) styrker behovet for udvikling af et intelligent energisystem.

Ved at lade ”alle dele kommunikere med alle dele” kan opnås bedre og billigere løsninger, end hvis energiforbruget et passivt element.

Også fjernvarme
En række analyser har handlet om prisfølsomt elforbrug. Imidlertid kan et intelligent energiforbrug også være relevant i fjernvarmesystemer. På grund af den termiske træghed er fjernvarme velegnet til kortvarige afbrydelser. En varmtvandsbeholder og gulvvarme kan bruges som energilager. De kan varmes op før de dyre timer eller kan kortvarigt afbrydes når prisen stiger.

De fleste af dagens tariffer for fjernvarme og for el-netselskaber er helt faste. Den samme betaling året rundt. Dette strider imod en omkostningsægte tarifering, hvor målet er at <u>forbrugeren betaler de omkostninger hans eller hendes energiforbrug afstedkommer</u>. I et typisk fjernvarmesystem med kraftvarme kan der være en faktor tre til forskel i de marginale omkostninger ved et ekstra varmeforbrug. Når varmen fx leveres af en kraftvarmeenhed er prisen lav, mens når den marginale varme leveres af en spidslast kedel, så er varmen dyr. Tarifferne burde afspejle dette for at være omkostningsægte.

Når tarifferne ikke er omkostningsægte vil der forekomme uhensigtsmæssigheder i den daglige adfærd og drift og i investeringsadfærden hos både forbruger og fjernvarmeselskab.

Der er en hønnen-og-ægget-situation. Når man ikke har målere, som fx kan opgøre energiforbruget per dag eller per time, så er der ingen nytte i dynamiske tariffer. Når tarifferne ikke er dynamiske, så er det svært at få økonomi i et intelligent forbrug. Hvis forbrugerne ikke er interesseret i dynamisk energiforbrug, så er der ikke økonomi i intelligente målere…

IT-mulighederne er på få år blevet så markante at sammenligning med tidligere tiders overvejelse ikke længere holder med hensyn til udbredelsen af et mere intelligent energisystem.

3. Teknologi
Mange forskellige design af styringssystemet kan tænkes. En væsentlig forskel er hvor intelligensen placeres. I nedenstående tabel er skitseret tre forskellige løsninger. Hvilken model, som bliver den mest udbredte kan afhænge af anvendelsesområde og de enkelte kommercielle leverandører kan gøre deres for at fremme deres model. Behovet for standardisering bør tilpasses, så alle tre løsninger tilgodeses.

[2] Se denne rapport for en god gennemgang af fordele ved prisfølsomt elforbrug: DOE (2006): Benefits of demand response in electricity markets and recommendations for achieving them. U.S. Department of Energy, February 2006.

Priser	Intelligens	Styresignal
Nord pool, nettariffer, reservebetaling m.m.	Centralt placeret hos tredjepart, fx som Devi's elvarmeløsning	Tænd/sluk eller ændrede set-punkter
	Lokalt i huset, fx som Innovus og Tell-it-online	
	Lokalt i det enkelte apparat, så der kan tages hensyn til apparatets tilstand og evt. kun afbryde dele af funktionen.	

Jeg synes ikke logikken i dette skema er helt indlysende. Hvad blev der af den annoncerede tegning ?

Fjernaflæsning og standard for "Åbent Hus"-kommunikation inde i boligerne
Energiselskaberne er ved at etablere fjernaflæsning af bygningernes energimålere der måler bygningernes samlede forbrug. Hvis forbrugerne reelt skal kunne agere på prissignaler er det imidlertid også behov for at kunne styre forbruget i de enkelte apparater og systemer. Dette sætter fokus på informationshåndtering og styring inde i de enkelte bygninger.

Hvor Internet til den enkelte bygning giver en veldefineret standard for kommunikation til den enkelte bygning findes der i dag ingen fast standard for kommunikation inde i bygningerne. På denne baggrund har Elsparefonden taget initiativ til en åben trådløs standard i i bygninger der kan sikre overvågning, måling og styring.

Behov for standardisering
Boliger og andre bygninger har behov for overvågning og behovsstyring, hvis unødvendigt energispild skal undgås. Den elektriske belysning behøver f.eks. kun at være tændt, når det naturlige dagslys er utilstrækkeligt og i øvrigt kun, når der er mennesker tilstede. Kort sagt, det er ikke nok at bruge energieffektivt udstyr – ydelserne skal tilpasses og optimeres i forhold til behovet over tid!

I de seneste 25 år er der talt meget om det "*intelligente hus*", der styrede de forskellige systemer i boligen efter det aktuelle behov og klima. Systemerne skulle samtidig bane vej for en række andre forbrugerrelevante tilbud – overvågning, Internet, underholdning m.m.

Disse koncepter har imidlertid kun opnået en begrænset udbredelse i boligerne til trods for at prisen på måle-, styrings- og kommunikations-udstyr i dag ikke burde være en reel hindring. Forklaringen på den ringe udbredelse skal findes i følgende to forhold.

For det *første* er der primært markedsført "lukkede" systemer, der ikke kan kombineres med andre produkter og koncepter. I et "lukket" univers er udvidelsesmulighederne begrænsede, og prisen på ekstraudstyr og tillægstjenester afspejler, at ofte høj.?????????

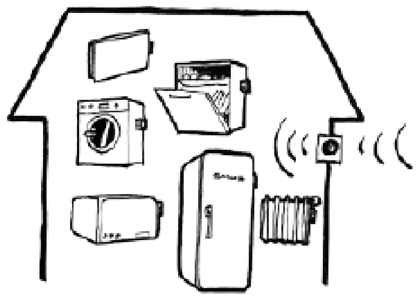
For det *andet* har tilbudene omhandlet ledningsbaserede løsninger med store installationsomkostninger og manglende fleksibilitet, når behovene ændres. I fremtidens velisolerede bolig vil elapparater med indbygget "intelligens" svare for ca. halvdelen af bygningernes samlede energiforbrug. En styring af disse apparater forudsætter en trådløs kommunikation.

Læren fra IT-verden:
De første it-systemer var mainframes, hvor én leverandør stod for den samlede leverance af hardware, devices og software. Disse systemer tabte til PC'erne, der med åbne kommunikationsstandarder og arbejdsdeling banede vej for et eksplosivt voksende marked, hvor et stort antal producenter og kompetencer konkur-

rerede. IT-sektorens voldsomme vækst, billiggørelse, kreativitet og appel hos forbrugerne havde ikke været mulig indenfor rammerne af lukkede mainframes-systemer.

Elsparefondens initiativ

For at fremme etableringen af et reelt marked for udstyr til måling og styring af energiudstyr i boliger har Elsparefonden taget initiativ til en *åben* og *trådløs standard* for kommunikation i boligerne "Åbnet Hus"-kommunikation.



Grundidéen er, at brugerne skal kunne kombinere forskellige 3. parts produkter og trinvis kunne udvide systemet i takt med, at behovet og udbuddet af produkter vokser. "Plug and Play" og et stort udbud af 3. partsprodukter skal gøre overvågning, måling og styring enkel og billig.

Elsparefonden vil markedsføre produkter, der overholder den åbne standard i en samlet forbrugerkampagne. For at understøtte denne markedsudvikling vil fonden udvikle hjemmesider og software, der kan integrere forskellige produkter samt gennem-analysere og styre boligernes energiforbrug. Dette koncept vil samtidig kunne bane vej for forskellige tilbud omkring forbrugerrespons på prissignaler. Det afgørende er at der ikke udvikles forskellige tekniske løsninger til henholdsvis afregning, elsparetiltag og fleksibelt elforbrug.

Udstyr til home automation findes allerede eller er på vej i år 2006

I vedlagte bilag er nævnt en række firmaer, som allerede har konkrete produkter på markedet eller på vej i 2006. Heraf ses, at der findes eksisterende teknologi, der allerede giver mulighed for fjernstyring af både el og varme, samt mulighed for overvågning af huset med hensyn til alarmer og elforbrug.

Et par af produkterne vil kunne måle effekten på det apparat de styrer. Disse effektmålinger kan bruges til overvågning af boligens energiforbrug. Endvidere kan de få en central betydning i forbindelse med effektregulering af elnettet, fx ved frekvensfald.

Fælles for samtlige produkter i bilaget er, at de kommunikerer via Z-Wave. (beskrivelse, henvisning ??) Det vil sige, at de kan kommunikere med hinandens produkter.

Fremtidens muligheder med de nuværende teknologier

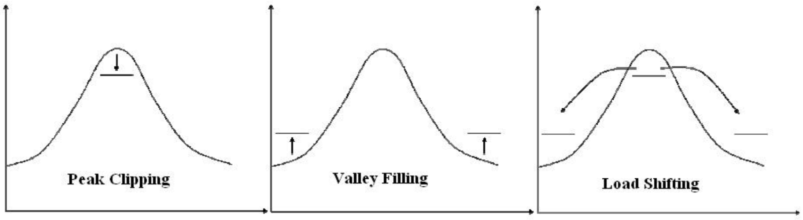
I dag installeres der allerede i de fleste nye produkter hardware til fjernkontrol. I forbindelse med produktionen af disse produkter vil der kun være en lille meromkostning forbundet med også at få systemet styret til at reagere på prissignaler. Styringen tænkes installeret enten direkte i produktet, eller via en central enhed i boligen.

Hvis udstyret får mulighed for styring som følge af prissignaler, åbner teknologien også op for andre muligheder, der blandt andre kan beskrives ved følgende tre scenarier:

Flytning af forbrug

Tænkes en opvaskemaskine at skulle startes om morgenen eller om aftenen, er det ofte ikke nødvendigt at den er færdig en time senere. Udstyres en opvaskemaskine med et antal valgmuligheder f.eks.; *Tænd nu*, *Tænd inden 3 timer*, Tænd inden 6 timer eller *Tænd inden 9 timer*, vil opvaskemaskinen starte, når det er økonomisk mest fordelagtigt for forbrugeren. Beslutningen om faktisk starttidspunkt tages automatisk enten på baggrund af en standard antagelse om prisens variation over døgnet eller på baggrund af en aktuel prisprognose, som udsendes af handelsselskabet sammen med tariffen.

Der opnås på denne måde fordele for både kunden og samfundet. Kunden opnår en økonomisk besparelse på elregningen, og samfundet opnår at noget spidslastforbrug flyttes til et andet tidspunkt.
Tilsvarende flytninger af energiforbrug vil ikke alene kun opnås ved opvaskemaskiner, men også ved fx rum- og vandopvarmning. Det er i den henseende vigtigt at bemærke, at forbrugerens komfort ikke påvirkes, da apparaterne stadig anvendes ud fra forbrugerens præferencer.

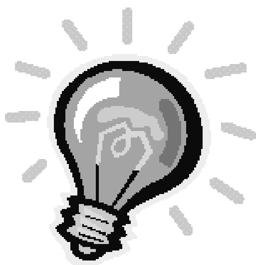


Enten bør dette figur forklares nøjere – eller også bør den udelades.

Elbesparelser
Hvis man ser direkte på elbesparelser kunne man forestille sig, at udstyret koblede valgte belastninger fra når elektriciteten er dyr. Der kan her også være tale om rumopvarmning eller udkobling af udvalgt belysning, hvilket både vil give en besparelse i kr. og øre for forbrugeren, men også en samfundsnyttig energibesparelse. Udkoblingen vil ikke påvirke forbrugerens komfort i disse tilfælde.

Ubalance i elnettet
I sjælende tilfælde opstår der en krisesituation i form af ubalance i elnettet og frekvensen falder. Her kunne man forestille sig at forbrugeren på forhånd har givet elforsyningen lov til udkobling af visse apparater. Dette mod en økonomisk kompensation. Herved er det muligt at forhindre en total ”black-out” af hele elnettet.

Med priselastisk elforbrug vil det give fordele for både forbrugere og samfundet, som nævnt i de tre ovenforstående scenarier. Det er vigtigt at fokusere på, at det er boligejeren, der i alle tre tilfælde skal afgøre hvilket udstyr der må udkobles, samt hvornår og hvor længe. Endvidere skal boligejeren altid have mulighed for at koble udstyret til igen.



Det er vigtigt at programmeringen af udstyret sker på en nem og overskuelig måde, med en engangsindstilling fx via en webside, hvorefter systemet virker per automatik.

Kommunikation i boligerne med åben og trådløs standard er en nødvendighed
Hvis de ovenstående scenarier skal blive til virkelighed og hvis udstyr, der kan styres efter prissignaler, skal få en stor udbredelse, er det nødvendigt at kommunikationen i boligerne bygger på en åben og trådløs standard. Derved kan brugeren udvide systemet i takt med at behovet og udbuddet

af produkter vokser. ”Plug and play” og et stort udbud af 3. part produkter skal gøre overvågning og styring enkel og billig.

Elsparefonden vil markedsføre produkter, der overholder den åbne standard i en samlet forbruger kampagne. For at understøtte denne markedsudvikling vil fonden udvikle hjemmesider og software, der kan integrere forskellige produkter samt analysere og styre boligernes energiforbrug

Stort potentiale i nyt udstyr – der er allerede regnekraft indbygget

Meget udstyr til automation og styring i boliger, som f.eks. lys og varme har allerede en CPU med program indbygget. Ligeledes er de fleste moderne hårde hvidevarer som vaskemaskiner, tørretumbler, opvaskemaskiner o.l. forsynet med en CPU og dermed programmeret styring. Det næste skridt er at tilføje kommunikation til apparatet, og derved kunne ændre i setup eller ændre apparatets tilstand. Kommunikationen tilføjes typisk for at øge apparatets ydelse. For hårde hvidevarer vil det være en besparelse i strømudgifter givet der er forskellige tariffer hen over døgnet. For lys og varme vil det ligeledes være muligt at opnå en reduktion i energi udgifter med en central nat- og feriestyring. Endvidere kan komforten i boligen øges med kommunikation mellem de enkelte systemer f.eks. giver kommunikation mellem en rumføler og en gulvvarme styring mulighed for at regulere temperaturen bedre, end hvis man f.eks. regulerer ud fra returvandets temperatur alene. Ligeledes øges komforten og driften optimeres med kommunikation mellem varme og ventilationssystemer.

Kommunikationen kan være trådløs så man undgår udgifter til trækning af kabler til det udstyr man vil automatisere.

Hvis man vil ”bygge” funktioner til fleksibelt elforbrug ind i apparater, der allerede har mulighed for kommunikation med andre dele af et home automation system, er det kun et spørgsmål om at udvide programmet med nogle ekstra linier for at opnå denne ekstra fordel. Apparater der ikke allerede har mulighed for kommunikation, men har intelligens indbygget, så som vaskemaskiner og tørretumblere, skal tilføres hardware i form af et kommunikations interface. Her findes der løsninger til trådløs kommunikation til under 20 DKK for en komplet radio til trådløs kommunikation, og denne pris forventes halveret i løbet af et års tid.

Z-wave kan blive en central teknologi

Firmaet Zensys, som har hovedkvarter i USA, men udviklingsafdelingen placeret i København, har udviklet teknologien Z-wave. Det er en chip med en dertil hørende software-protokol, som muliggør to-vejs kommunikation i et selvorganiserende netværk, og som på grund af lav pris og lavt energiforbrug er velegnet til home automation. Protokollen sikrer at når en ny komponent bliver tilført hjemmet, indgår den automatisk i netværket. Blandt andet Danfoss anvender denne teknologi i nye versioner af deres termostater.

Timemålere

I Italien afsluttes i år et projekt som giver 30 millioner kunder en fjernaflæst elmåler. I Australien og Storbritannien har regulator udgivet cost-benefit analyser som påpeger det hensigtsmæssige i at udrulle fjernaflæste målere til alle forbrugere[3]. I Sverige vil praktisk talt alle kunder have fjernaflæste elmålere i 2009.

[3] OFGEM: Domestic Metering Innovation. Consultation, February 2006. ESC: Mandatory rollout of interval meters for electricity customers. March 2004

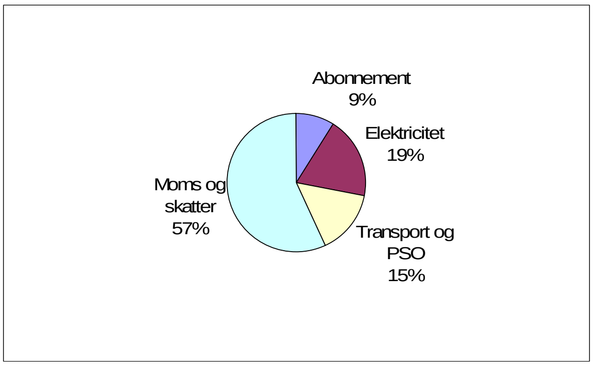
Sydvest Energi har installeret fjernaflæste måler hos 40.000 af deres kunder og vil have nået alle 136.000 kunder i 2007. Også NESA, Odense Energi og Energi Fyn investerer i fjernaflæste målere. Disse eksempler svarer til 8% af elmålerne i Danmark.

Der er behov for en plan for udrulning af fjernaflæse energimålere i Danmark, herunder at sikre at indtægtsrammeregulering eller anden regulering ikke står i vejen for en sådan udrulning.

EU's Energiservice-direktiv, som forventes vedtaget dette forår, peger på nytten af gode målere: "Member States shall ensure that .. final customers .. are provided with .. individual meters .. that provide information on actual time of use. When an existing meter is replaced, such .. meters shall always be provided .." (se note for den fulde tekst[4]). Dette kan være en anledning til en afbalanceret plan for en udrulning af intelligente målere i Danmark.

4. Priser og tarifer

For en almindelig husholdninger koster elektricitet 1,80 kr/kWh, men det er kun 19% af den samlede betaling, som er den rene energibetaling[5]. Transport og PSO udgør 16%. Moms og skatter udgør over halvdelen af betalingen.



Dynamiske priser og tariffer

Hvis det eneste omkostningselement i den samlede elregning, som varierer, er selve energien (spotprisen), så er det økonomiske potentiale for besparelser begrænset. Et eksempel viser at der kan spares 100 kr. for en elvarmekunde (som reducerer forbruget med 5%, når prisen øges med 10% – og forøger forbruget tilsvarende ved faldende priser).

Netselskabernes tarifer dækker primært transport af elektriciteten. Omkostninger til transport er stærkt varierende over tid, men tarifferne afspejler ikke dette. Principperne om marginal prissætning tilsiger en varierende betaling. Når tabet i distributionssystemet er stort og når kapaciteten er ved at være fuldt udnyttet bør betalingen for transport være høj. En omkostningsægte tarifering af transport af el vil delvist svinge i takt med spotpriserne – alene af den grund at tabet afregnes til spotpriser.

Energiafgifterne burde ideelt set også variere over tid. Tager man udgangspunkt i at afgifterne skal forvride det bagvedliggende prissignal mindst muligt, så er svaret ikke konstante afgifter (kr/kWh), men nærmere afgifter som varierede med de bagvedliggende priser. Dette kunne være proportionalt med priserne (en fast %) eller en forenklet version, fx med en højere beskatning om dagen, hvor priserne generelt er højest. Det er en misforståelse af faste afgifter ikke forvrider.

---

[4] §13.1: Member States shall ensure that, in so far as it is technically possible, financially reasonable and proportionate in relation to the potential energy savings, final customers for electricity, natural gas, district heating and/or cooling and domestic hot water are provided with competitively priced individual meters that accurately reflect the final customer's actual energy consumption and that provide information on actual time of use.
When an existing meter is replaced, such competitively priced individual meters shall always be provided, unless this is technically impossible or not cost-effective in relation to the estimated potential savings in the long term. When a new connection is made in a new building or a building undergoes major renovations as set out in Directive 2002/91/EC, such competitively priced individual meters shall always be provided.
[5] Energitilsynet, november 2005.

Ovenstående regneeksempel viser at hvis alle priselementer varierede efter spotprisen (men med samme årlige betaling), så ville besparelsen øges fra 100 kr til 2.900 kr per år. Med intelligente tariffer, som varierede efter de relevante forhold, som er nævnt ovenfor, er det realistisk at besparelsen ved at tilpasse forbruget kan nå 1.000 kr. per år for en husholdning med elvarme eller et hus med fjernvarme.

I elsystemet er der flere elementer, som kan øge incitamentet for dynamisk energiforbrug. Dette handler om:

- At muliggøre at husholdninger kan levere regulerkraft og reserver. Traditionel leveres disse relativ dyre ydelser fra produktionsanlæg, men de kan også leveres af forbrugssiden. I visse tilfælde kan forbrugssiden faktisk levere hurtigere reserver end produktionssiden. Der er behov for udvikling af procedurer m.m. for at dette kan udnyttes effektivt. På tekniksiden gælder det at timemålere er en forudsætning.
- At udvikle en dynamisk tarifering til at dække omkostningerne til reserver m.m. Fx behovet for at reservere regulerkraft varierer stærkt, og er fx afhængig af om transmissionsforbindelserne er fyldte. En dynamisk tarif kunne afspejle dette og øge incitamentet til at flytte forbruget i tid.

Hønen-og-ægget-situationen må brydes. Politikerne har en vigtig rolle i denne opgave.

5. Rollefordelning

Netselskaberne har en stor rolle med hensyn til at udrulle fjernaflæste elmålere. Dette er deres opgave og de har kompetencen. Det er endvidere et monopolområde. De målte data bør på en moderne måde stilles til rådighed for forbrugerne. Dette kan fx ske – som allerede praktiseres af mange netselskaber og af Elsparefonden – via Internettet, hvor tal og kurver kan præsenteres og konsekvenserne for omkostningerne kan beregnes.

Der kan evt. også være brug for at kunderne selv direkte kan tilgå målingerne. Dette kan fx ske via en puls udgang, som kan opsamles lokal. Dette kan give real-tids data for forbruget. Netselskabet vil typisk hente data hjem hver nat, således at de først kan vises med en døgns forsinkelse.

I forbindelse med Energy trader og det intelligente energisystem er der to nye kommunkationsstrømme, som også skal findes deres plads. Dette er dels fremsendelse af aktuelle priser (dagligt eller i real-tid), og dels fremsendelse af styresignaler til det udstyr som skal reagere på priserne.

En række forhold taler for at lade disse signaler løbe af andre veje end elmåleren. Anvendes i stedet mere generelle kommuniationsveje, som Internettet og mobiltelefoni kan der opstå et langt større kommercielt marked på dette område. Handelsselskaber kan konkurrere om måde at fremsende priserne og leverandører af styringsudstyr kan konkurrere på både udstyr om måder at styre dette.

Handelsselskaberne vil i fremtiden have en vigtig rolle med at udvikle en samlet tarifering, som dække energiprisen (fx elspot og elbas) og de forskellige reserver (regulerkraft og andre reserver). Forskellige handelsselskaber kan konkurrere om at tilbyde tariffer, som kan gøre automatisk tilpasning af elforbruget, attraktivt. Konkurrencen kan også omfatte at fremsende (pris-)signaler, som er kompatible med kundernes automatikudstyr.

6. Bidragsydere
Denne tekst er udarbejdet på baggrund af Energy Camp 05, hvor gruppe 2 udstak ideerne til Energy Trader. Udover Gruppe 2, så har en større gruppe medvirket aktivt i denne proces.

Energy Camp 05, gruppe 2:
Pia Rasmussen, DTU.
Hanne Jersild, Vindmølleindustrien
Lars Landberg, Risø
Martin Wittrup Hansen, DONG
Svend H. Andersen, Arcon
Niels Vilsbøll, Vestas
Carl Helmers, Fredericia Fjernvarme
Mikael Togeby, Energinet.dk (nu Ea Energianalyse)

Skrivegruppe, som har skrevet denne tekst:
Søren Hansen, Danfoss
Thomas B. Houberg og Thomas K Bauer, Innovus
Mikael Koch, Erik Herløv Design og Tell-it-online.
Carl Hellmers, Fredericia Fjernvarme
Niels Vilsbøll, Vestas
Göran Wilke, Elsparefonden
Knud Ole Helgesen Pedersen, Helena Segerberg, DTU
Ebbe Munster, PlanEnergi
Mikael Togeby, Ea Energianalyse

Vi modtager gerne kommentarer til denne tekst. Kontaktperson: Mikael Togeby, 60 39 17 07, mt@eaea.dk.

Bilag: Eksempler på udstyr til home-automation

Dette bilag giver en oversigt over nogle af de fabrikanter og deres produkter som findes på markedet eller som kommer på markedet i 2006 og som anvendes i forbindelse med home-automation.

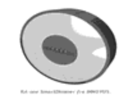
Danfoss har fjernstyret gulvvarme og termostater til radiatorer, der giver mulighed for indstilling af de enkelte værelsers temperaturer. Endvidere giver varmesystemet mulighed for at indstille forskellige dag og nattemperaturer. Danfoss´ kompressorer til køleskab og aircondition er i dag ikke fjernstyrede, men dette kan indbygges uden den helt store meromkostning, når dette bliver aktuelt.

I 2006 kommer Danfoss med termostater til radiatorer, der vil kunne styres med Innovus og Tell-it-onlines udstyr, jf. nedenfor.

Med udstyr fra det norske firma **HusetMitt** er der mulighed for overvågning af boligen, for at kontrollere om lyset er tændt eller slukket, om et vindue er lukket, samt om strygejernet eller kaffemaskinen er slukket, samt kameraovervågning.

Udstyret bygger på små radiomodtagere der indsættes i stikkontakterne. En central enhed i boligen styrer apparaterne i de forskellige stikkontakter. På en computer med internetforbindelse kan et ugeprogram indlægges for varme- og lysstyring. Her kan man indlægge hvilke temperaturer der ønskes på forskellige tidspunkter i de forskellige værelser. Ligeledes er der mulighed for at indlægge et belysningsprogram for huset.

Firmaet **Innovus** kommer med flere forskellige typer udstyr i 2006. I den nærmeste måned vil man kunne finde en Innovus lysdæmper, der kan fjernstyres lokalt, på markedet. I tilslutning til de forskellige lysdæmpere vil være muligt at tilkoble et panel med 4 kontakter, eller en fjernbetjening, hvor der er muligt at centralt styre belysningen. Her er det muligt at fra en forudbestemt indstilling vælge hvilke lamper der skal være tændt samt hvilken lysstyrke disse skal have. I lysdæmperen er der indbygget en mulighed for effektmåling.



Innovus vil til efteråret udkomme med en enhed til central styring og overvågning af boligens el, lys, varme og alarmer. Styringen kan foretages både indendørs og udendørs. Brugerfladen kan være en computer, mobiltelefon eller pda.

Til efteråret vil firmaet **Tell-it-online** introducere et produkt på markedet med mange funktioner indbygget, bl.a. radio, musik, telefon, e-mails, styring og overvågning af for eksempel lys, varme og elforbruget på apparater. Produktet virker helt uden brug af separat computer. Produktet har indbygget en højtaler og en lille skærm med touch-screen, dvs. brugeren kommunikerer ved berøring af skærmen. Skærmen vil oftest være slukket. Enheden kommunikerer med forskellige enheder, der indsættes i stikkontakterne.

Også dette produkt vil have mulighed for effektmåling af forskellige apparater.

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Ebbe Münster, PlanEnergi, Denmark
E-mail	em@planenergi.dk
Title of dissemination	Comparison of Electricity Balancing for Large Scale Integration of Renewable Energy in six European Regions.
Type of activity	Oral presentation and article for journal
Title of forum	Dubrovnik Energy Conference 2007.
Language	English
Date of dissemination	June 3-8th , 2007
Place of dissemination	Dubrovnik, Croatia.
Brief abstract / description of dissemination activity	This paper addresses the question of balancing fluctuating electricity productions from renewable energy sources in Europe a) by the use of additional capacity of interregional transmission lines versus b) by increasing the balancing capacity of the regional production and distribution system. The aim has been to identify technologies and in particular mix of technologies which will enable the increase in fluctuating and unforeseeable electrical productions which will be the result of the fulfilment of the current EU energy plans. It is found that new transmission lines often cannot compete economically with measures to improve the internal balancing potential of the regions involved. Part of the reason for this is the large costs and long planning periods involved in the strengthening of the internal transmission networks which are necessary to distribute the increased exports and imports. The fundamental changes of the production and distribution systems for electricity which are mainly caused by the rapid development of the information technology and the liberalisation of the markets are shown to have a positive potential for the growing balancing requirements. The scenario analyses have been carried out for the electrical production and consumption systems in six regions in Denmark, Estonia, Germany, Great Brittan, Spain, and Poland.
Audience impact assessment	N/A
Dissemination	Included after this form

Comparison of Electricity Balancing for Large Scale Integration of Renewable Energy in six European Regions.

Dr Ebbe Münster*
PlanEnergi
Jyllandsgade 1, Skoerping, DK 9520 Denmark
e–mail: em@planenergi.dk

Professor Henrik Lund
Department of Development and Planning.
Aalborg University, Fibigerstraede 13, Aalborg, DK 9220 Denmark.
e–mail: lund@plan.aau.dk

ABSTRACT

This paper address the question of balancing fluctuating electricity productions from renewable energy sources in Europe a) by the use of additional capacity of interregional transmission lines versus b) by increasing the balancing capacity of the regional production and distribution system. The aim has been to identify technologies and in particular mix of technologies which will enable the increase in fluctuating and unforeseeable electrical productions which will be the result of the fulfilment of the current EU energy plans. It is found that new transmission lines often cannot compete economically with measures to improve the internal balancing potential of the regions involved. Part of the reason for this is the large costs and long planning periods involved in the strengthening of the internal transmission networks which are necessary to distribute the increased exports and imports. The fundamental changes of the production and distribution systems for electricity which are mainly caused by the rapid development of the information technology and the liberalisation of the markets are shown to have a positive potential for the growing balancing requirements. The scenario analyses have been carried out for the electrical production and consumption systems in six regions in Denmark, Estonia, Germany, Great Brittan, Spain, and Poland.

THE DESIRE PROJECT

The DESIRE project addresses the balancing of the forecasted increased amount of fluctuating and unpredictable electricity production in Europe. [1]
It has been carried out in the framework of EU-FP6 by 10 European companies and universities headed by Aalborg University. It was concluded May, 31st 2007.
A number of technologies with balancing potentials have been investigated using six chosen regions throughout Europe as cases. The methodology has been to analyse the balance of the electrical grid of each region as a whole and to compare various mixes of production and regulating technologies with respect to the ability to assist in minimizing either the need for forced exchange of power with the neighbouring regions or the total socio economic costs of electricity production of the region.

* Corresponding author

In the scenario analyses used to identify the best technologies, optimal use of all parts of the electrical system has been assumed on an hourly basis for a whole year. This is a sound assumption to make when the purpose is to find the best solutions from a technical point of view, but it is of course an ideal, which it is difficult to achieve in practice. In parallel parts of the project the economic and bureaucratic barriers have been addressed.

THE SIX REGIONS

The following countries have been involved in the DESIRE project: Estonia, Denmark, Germany, Poland, Spain, UK.

For each country a region suitable for simulation has been selected. The criteria used are:

1. Large enough to include both fluctuating electricity production (e.g. wind turbines) and power plants with regulation capacity (Combined-Heat-and-Power plants - CHP)
2. Small enough not to have important internal bottlenecks (one price area)
3. Well defined boundaries.
4. Available data (for 2004 plus forecasts for 2020).

The results of the selection were:

- Estonia - the whole country
- Denmark - the western part (Jutland and Funen)
- Germany - the whole country
- Poland - the whole country
- Spain - the whole country (minus the islands)
- UK - the southern part of Scotland (Fig. 1)

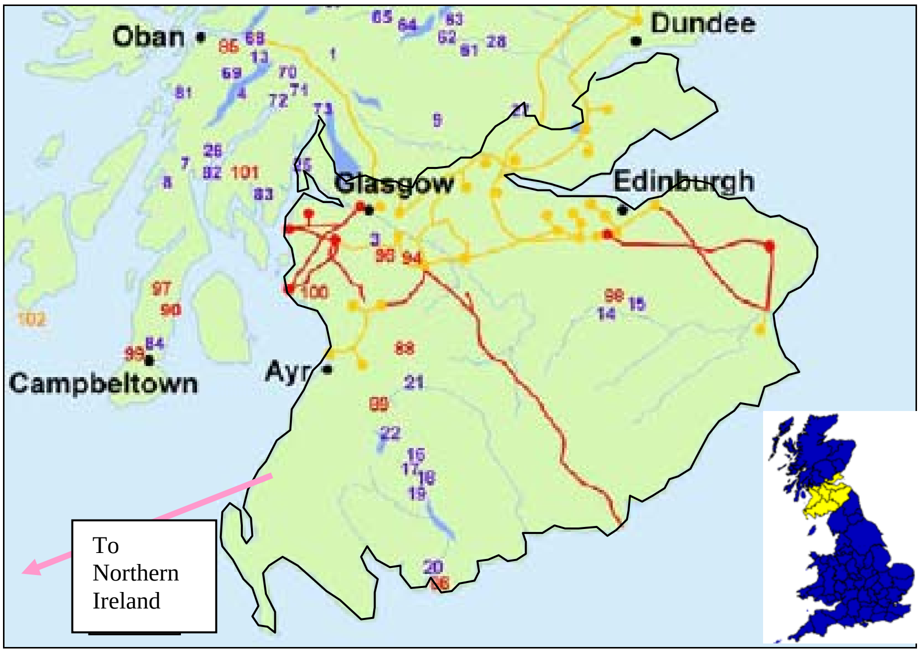


Figure 1. UK calculation region.

Reference calculations

Simulations of the energy systems in the selected regions had a number of different purposes during the project:

- Calculations of how the present and future energy systems can improve the capability of incorporating fluctuating electricity production (e.g. wind turbines) by optimising regulation strategies.
- Calculations of how changes in the flexibility of the electricity production units (e.g. by increasing heat storages at CHP plants) influence the electricity balance in scenarios with growing share of fluctuating and unpredictable electricity producers.
- Calculations of how changes in the flexibility of the electricity consumption (e.g. by the introduction of battery cars) influence the electricity balance in scenarios with growing share of fluctuating and unpredictable electricity producers.
- Calculations of various scenarios concerning the question of establishing new international transmission lines versus increasing the flexibility of the production and consumption in the electricity system.

The simulation software, EnergyPLAN, which has been developed by Aalborg University and other partners in the project, was used for the simulations.
It is an input-output model, which uses data on capacities and efficiencies of the energy conversion units of the system and availability of fuels and renewable energy inputs.
Hour by hour it calculates how the electricity and heat demands of society will be met under the given constraints and regulation strategies.
Fig. 2 gives an impression of the functioning of the model. It is seen how it concentrates on the electrical system but incorporates other parts of the system which interact with it.
The result of the calculation is a detailed knowledge on the production of the different units. From this, fuel consumption can be calculated and subsequently the socio-economic costs and CO_2 emissions caused by the of meeting the demands of the society can be found.
The model is described in detail in delivery D 1.5 of the DESIRE project [1]. It can be downloaded free of charge from [2] including a comprehensive manual.
The process of collecting the necessary data and carrying out the reference calculations for 2004 and 2020 is described in deliveries D 1.1 and D 1.3 [1].
In this process determination of fuel prices and electricity market prices for 2020 constituted a special problem. For all data official forecasts have been used when available, but the forecasts for prices depending on the oil price were too different. This can be explained by different attitudes regarding the development of the oil price. In Denmark and Spain, the official IEA forecast has been used, in which the present high level of oil prices is expected to be intermediate, while other countries have more pessimistic (realistic?) approaches. To make the calculations comparable it was decided to use two sets of standard data for oil, N-gas and electricity. A low price scenario, 2020a, corresponding to the first attitude (26 $/brl) and a high price scenario, 2020b, corresponding to the latter (100 $/brl).
Examples of the assumed prices for N-gas and electricity is shown in figure 3. As the calculations are dealing with socio economy only, the shown prices are estimates of international wholesale market prices. On top of these prices an estimate of the 2020 price of CO2-certificates is taken into account (13,3 €/t).

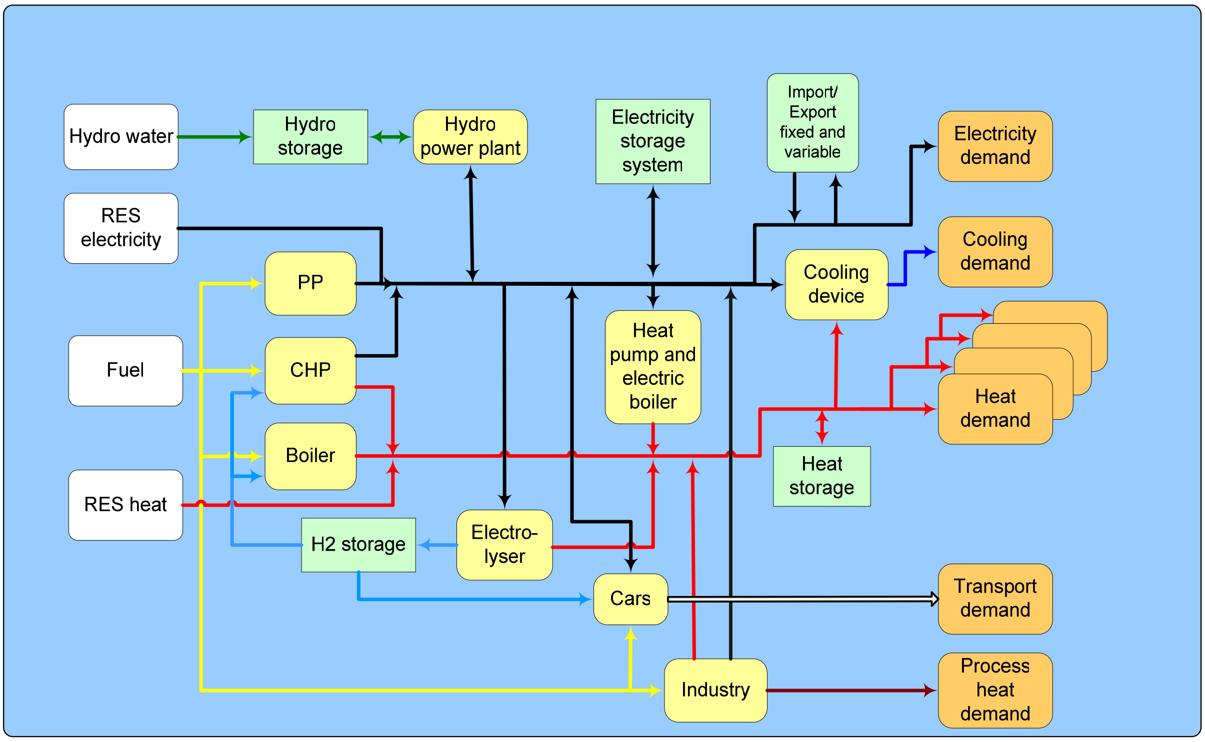


Figure 2. The EnergyPLAN model.

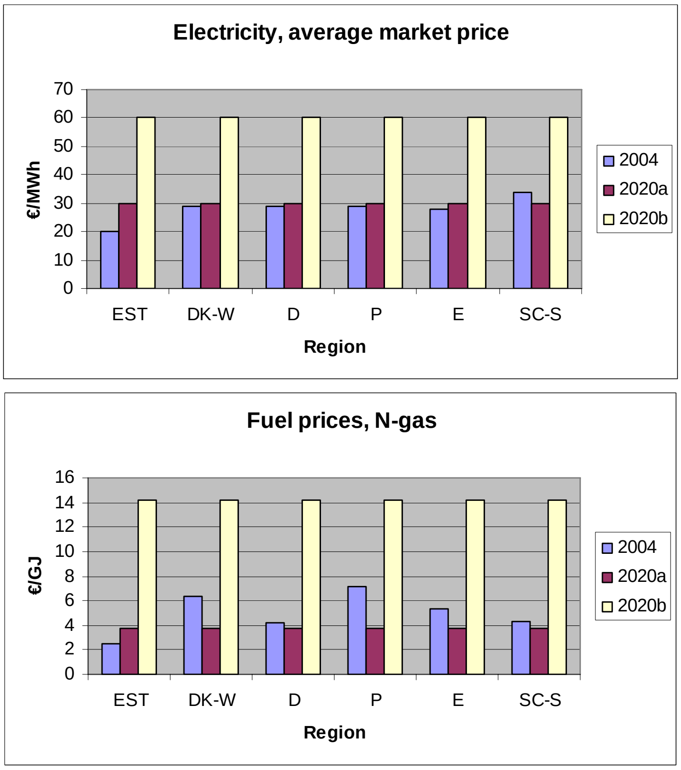


Figure 3. Assumed market prices.

IMPORTANT BALANCING TECHNOLOGIES

Electricity production technologies

The most important production technology considered is the co-production of electricity and heat at small (< 25MW) or large power plants. In particular when such plants are equipped with heat stores corresponding to the daily heat production they have a very significant balancing potential apart from a high overall efficiency. In Denmark this technology has been promoted for the last 20 years and a share of app. 60% of the total production of electricity has been achieved. The level in EU in general is much lower, but lately a specific promotion programme has been launched. The main reason for this is not the balancing potential but the fuel savings involved in the increase of overall efficiency.

The technologies used for CHP are mainly N-gas engines at the small plants and extraction steam turbines at the large plants (mainly coal fired).

In the project also micro turbines, fuel cells and stirling engines have been analysed for small plants or even households.

Hydro turbines with reservoirs and eventual reverse pumping capacity also have large balancing capacities, but they have the disadvantage of being difficult to establish. The present plants can seldom be enlarged.

Conversion and storing technologies

The use of large heat pumps (> 1 MWe) at the CHP plants will enable these to shift from electricity production to electricity consumption in a matter of minutes without loosing the heat production capacity. If the efficiency of the heat pump is sufficient the overall efficiency of the system will not decrease. The only disadvantage is the investment and operation costs of the heat pump.(see German case below).

Storing heat is simple but storing electricity is still difficult and expensive. The following technologies have been looked into: hydrogen and electrolysers, compressed air, reverse pumping, batteries (in particular in connection with battery cars – see Spanish case below).

Regulating technologies

Demand-Side-Management (DSM) has been analysed in particular in connection with heating, ventilating and cooling of houses. In this connection the use of district cooling has been considered.

Use of interconnectors

In principle imbalances in one region can be balanced by the neighbouring regions if interconnectors have sufficient capacity and commercial availability. This method is particularly relevant when the regions have different profiles regarding electricity production or consumption. The balancing of German wind power by Austrian hydro power is an example of such a situation. The economic and physical planning difficulties in establishing new power lines, however, are huge and often internal measures as described above are preferable. (see Danish case below).

THREE CASES

Increasing capacity of interconnectors (Denmark)

In order to investigate the economy in solving the balancing problem involved in a considerable increase of wind power in Denmark a situation is considered where the capacity of wind power is gradually increased from the present 20% to about 120% of the electricity demand. The economic consequence of doing this is shown below in figure 4.

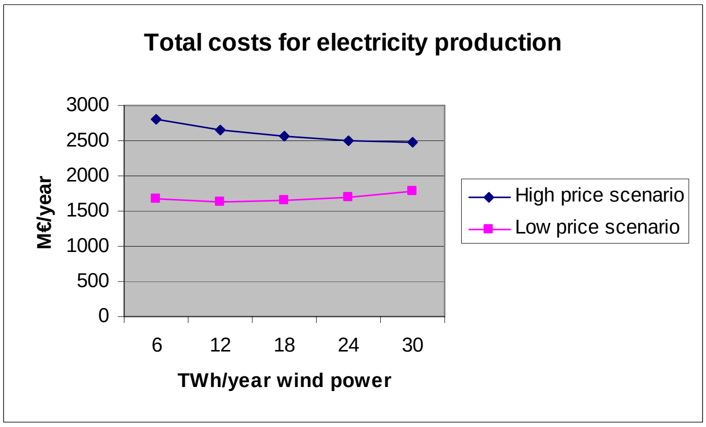


Figure 4. Costs of production at various levels of wind power.

It is seen how very high levels of wind power are profitable in the high price scenario, whereas a minimum level of costs is reached at a level of 12 TWh/year in the low price scenario. It is noted that socioeconomic costs only are considered and that a low interest rate of 3% without inflation is assumed. Often much higher rates are used for this kind of calculations causing much lower levels of renewable energy technologies to be feasible. The low rate is used for the following reasons:

- This interest rate is close to the rate which is to day obtainable in Denmark for long term investments in e.g. insulation projects.
- It resembles the rate used when long term environmental and health effects of energy investments are assessed. (like in the ExternE project [3])
- That long term energy investments compete with other investments like in the export industry and hence should ‘pay’ the same interest rate is an argument often used but not valid. Such other investments depend on cheap and reliable supply of energy. In other words: It might be that it is more profitable to invest in trains than in rails, but sooner or later this strategy will prove unsustainable.[4]

Part of the reason for the falling marginal profit of wind power at higher levels of production is that the assumed capacity of interconnectors to Norway/Sweden and to Germany, 1700 MW, becomes unable to balance the fluctuating production despite utilisation of the CHP´s for balancing (4850 MWe with 25 GWh thermal stores). This means that Critical Excess Electricity Production (CEEP) would occur if special measures, which are economically unwanted, were not taken into use. Table 1. shows the measures used in the above calculation to maintain the balance of the Western Denmark region in the case of 30 TWh/year wind power. It is stressed that the measures shown in table 1. are used at high levels of wind power only and only after all economically sound measures like making use of the heat stores of the CHP’s have been fully exploited.

Table 1. Avoiding critical excess production at 30 TWh/year

CEEP – reduction, TWh	Low prices	High prices
Reduce CHP production, (increase boiler heat production)	5,21	2,04
Use electric boilers at CHP	4,01	4,38
Reduce wind power by stopping wind turbines	3,44	3,10

The methods shown in table 1. are used from top to bottom, which means that the actual stopping of turbines is used as the last (and most uneconomic) resort.
If an attempt is now made to solve the balancing problem at high levels of wind power by adding 1000 MW of new capacity to the interconnectors the following results are obtained.

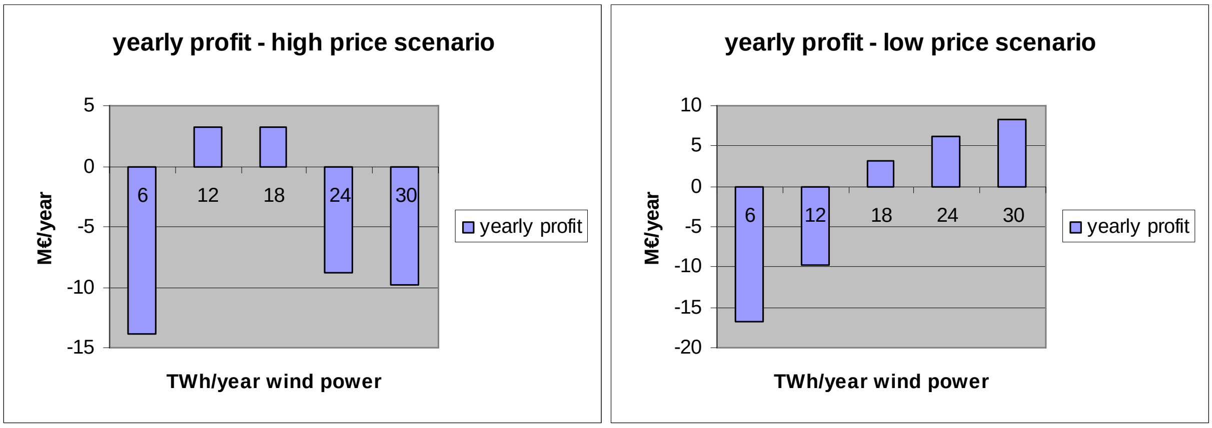


Figure 5. Profit of increasing interconnector capacity with 1000 MW.

It is seen that the additional capacity pays only in some situations. And it is noted that it does not pay in the situations where the wind power provides maximum benefit. Hence the investment is questionable.
In the above calculation the total investment for the1000 MW interconnector is assumed to be 300 M€. (lifetime 30 years, O&M 0,5% of investment). An interregional transmission line normally requires costly strengthening of the internal grid. The total cost in the actual case is based on analyses carried out by the Danish Energy Agency [5].

Adding heat pumps to combined-heat-and-power plants (Germany)

The forecasts for electricity production in Germany for 2020 call for 23 GWe of CHP capacity and 45 GWe of wind turbines. They contribute 17% and 26% respectively of the electricity production (app. 500 TWh/year).
This amount of wind power can easily be balanced. One reason for that is the strong interconnector capacity of 17 GW.
It should be noted that critical excess electricity production will start to occur if the wind power share is increased to more than 50% of the demand.
In this situation the effect of installing 5 GWe of heat pumps with a COP of 3 is investigated.
The low temperature heat source could be condensing cooling of exhaust gas from N-gas engines.(e.g. 20 dg.C) stored in a low temperature heat storage.

The economic result of this calculation is shown in figure 6.

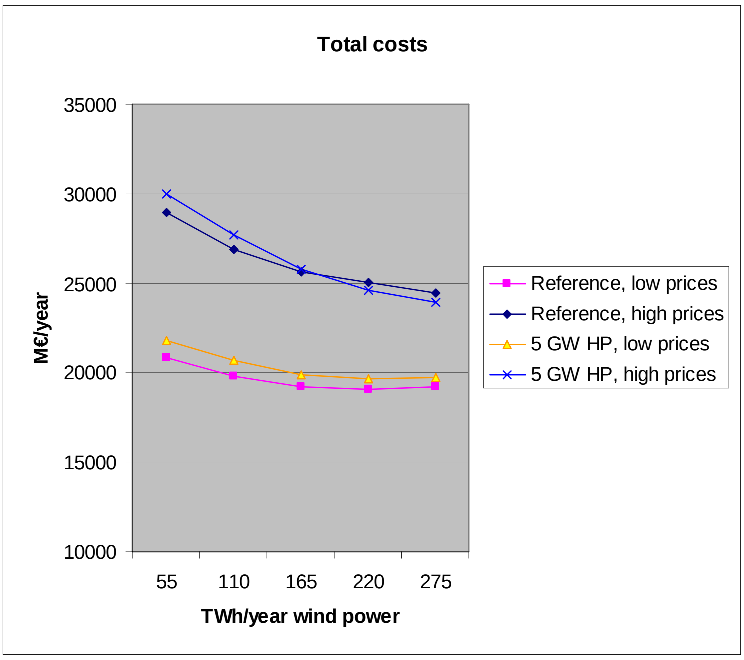


Figure 6. 5 GWe heat pumps, Germany.

Figure 6 shows that the investment in heat pumps pays in the high price scenario only. The hybrid effect of heat pumps and wind turbines,however, is seen by the way the heat pumps increase the marginal value of the wind power in the whole range of the variation (faster decrease of costs at increasing level of wind power).

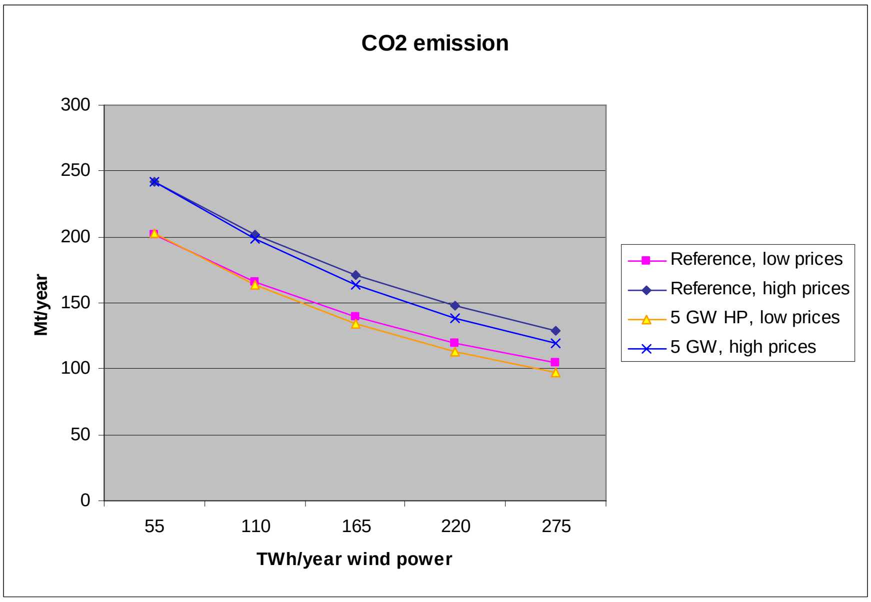


Figure 7. CO2-effect of heat pumps.

Finally the environmental effects of the heat pumps are assessed. It can be seen from figure 7 that the heat pumps have a clear positive effect on CO2-emissions regardless of the prices and the wind power levels. This shows that they do not lower the overall efficiency of the system.

Introducing battery cars (Spain)

The projected situation for Spain in 2020 is that 25 GWe of wind power provides 22% of the total demand (app 380 TWh/year) while hydro power provides 9%, nuclear 17% and conventional power plants 41%. CHP is negligible.
The hydro plants have some regulating capacity, but the conventional plants provide most of the balancing. The interconnectors to France, Portugal and Morocco are weak (total app. 2000 MW).
New technologies with balancing potential must be introduced if further increases in the wind power capacity are wanted. In this case the possibility of involving the transport section is investigated. The assumption is made that 20% of all cars will be changed to battery cars. The necessary electrical power to maintain the former amount of transport work is calculated to be 13 TWh/year. Because of the high efficiency of battery cars compared to petrol cars this electricity in turn substitutes 60 TWh petrol and lower CO2 emission with 15,9 Mt CO2. The cost of the investment is assumed to be 80% more than the corresponding petrol car, which is valued at 11000 € (socio economic costs). It is underlined that the estimate of the extra cost prices is based on today's technology. In 2020 they are probably much lower.
To maximise the balancing use of the batteries in this great number of cars the so-called Vehicle-to-Generator (V2G) operation is assumed. According to this method the owners of the cars are motivated to keep the cars connected to the grid whenever they are not in use. This will make it possible for the system operators to load and to unload the batteries according to the balancing needs of the system. An intelligent control system in each car ensures that sufficient energy is available for the battery when it is needed by the owner. Figure 8. below shows how this function in practice. In the shown situation the left graph shows how the electricity demand is met in a situation with a high level of wind power, i.e. 75% of total yearly demand and without the battery cars. The right graph shows how the batteries are used to lower the production of the power plants (yellow=storage). The energy for this purpose has been loaded into the batteries at times, where a surplus of power would otherwise have caused some turbines to be stopped.

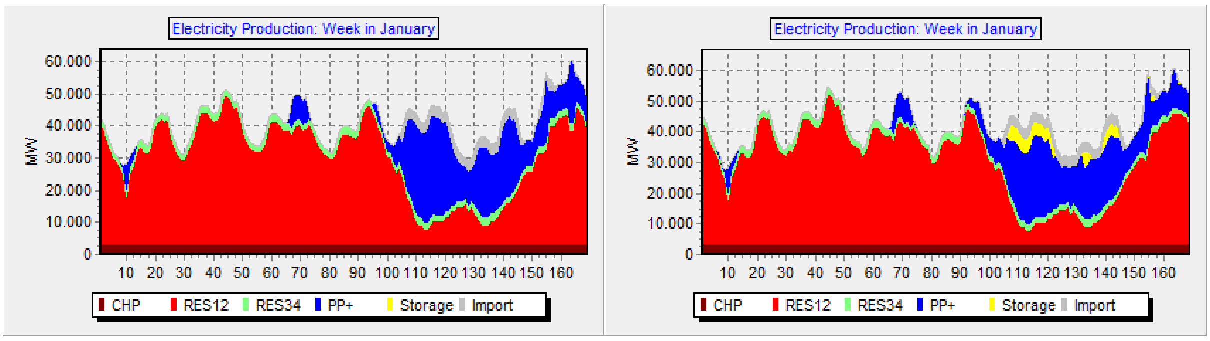


Figure 8. Production without (left) and with (right) battery cars.(RES12=wind power, RES34=hydro power and photo voltaic, PP=power plant).

The economy of the investment and the operation of the cars are shown in figure 9. It shows that the heavy investment in the battery cars is not justified in the low price scenario, but in the high price scenario they provide a profit and a clear increase of the marginal profit of wind power.

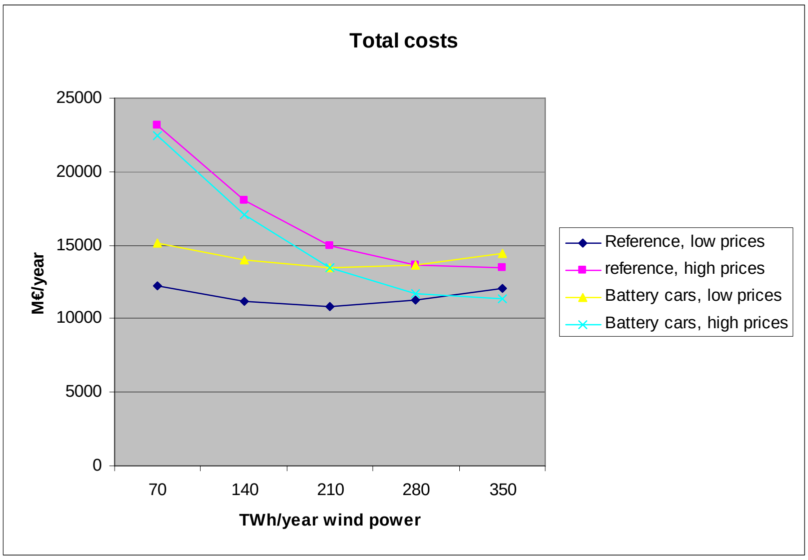


Figure 9. Economy of battery cars.

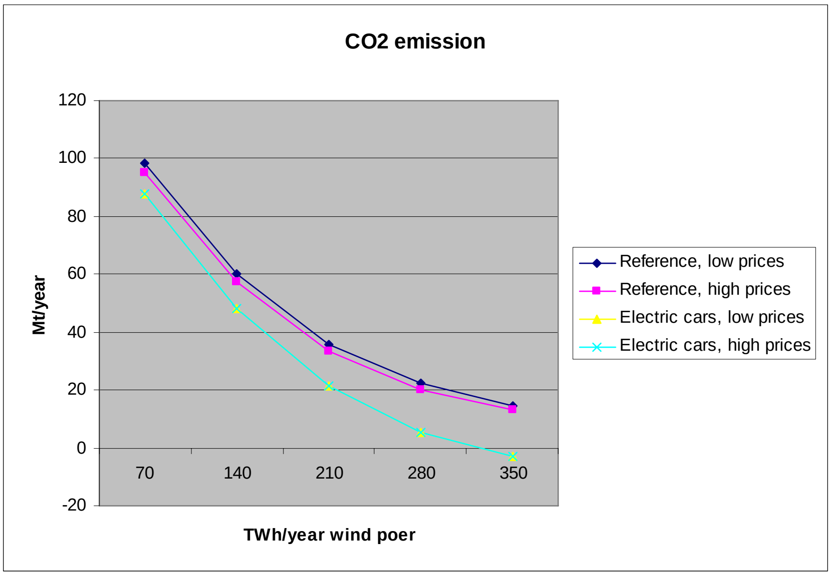


Fig 10. CO2 emissions, battery cars.

Finally figure 10 shows the effect on CO2 emissions of the battery cars. It can be seen that the decrease of emissions is not just due to the fuel substitution. It increases with higher levels of wind power because the regulating capacity becomes more and more important.

NECESSARY STRUCTURAL CHANGES IN THE DISTRIBUTION NETWORK

The energyPLAN scenario calculations referred to above assume that a perfect market (or a centralised control system) allocates the production capacities hour by hour in a way which ensures either minimum excess electricity production or minimum socio economic costs of production. This is a sound methodology when the aim is to compare the potential of different capacity mixes or different control strategies, but it does not give a realistic picture of the functioning of the partially liberalised electricity market today.
The reasons for this are analysed in a number of deliveries of the DESIRE project [1]. However, this situation is being improved as both the markets and the technical systems are changing at considerable speed in the direction of more intelligence and flexibility.

This process has been studied by a number of EU projects and lately in the EU SmartGrid Technology Platform, which was launched in April 2006. The text below and in Figure 11 show how the process involves many topics from microgrids to Smarter use of transmission lines.

Electricity grids of the future are Smart in several ways. Firstly, they allow the customer to take an active role in the supply of electricity. Demand management becomes an indirect source of generation and savings are rewarded. Secondly, the new system offers greater efficiency as links are set up across Europe and beyond to draw on available resources and enable an efficient exchange of energy. In addition, environmental concerns will be addressed, thanks to the exploitation of sustainable energy sources. The potential benefits are impressive, but how will they be achieved?

The platform in turn relies partly on the finding of the projects in the FP5 cluster: IRED. Among them DISPOWER and CRISP.

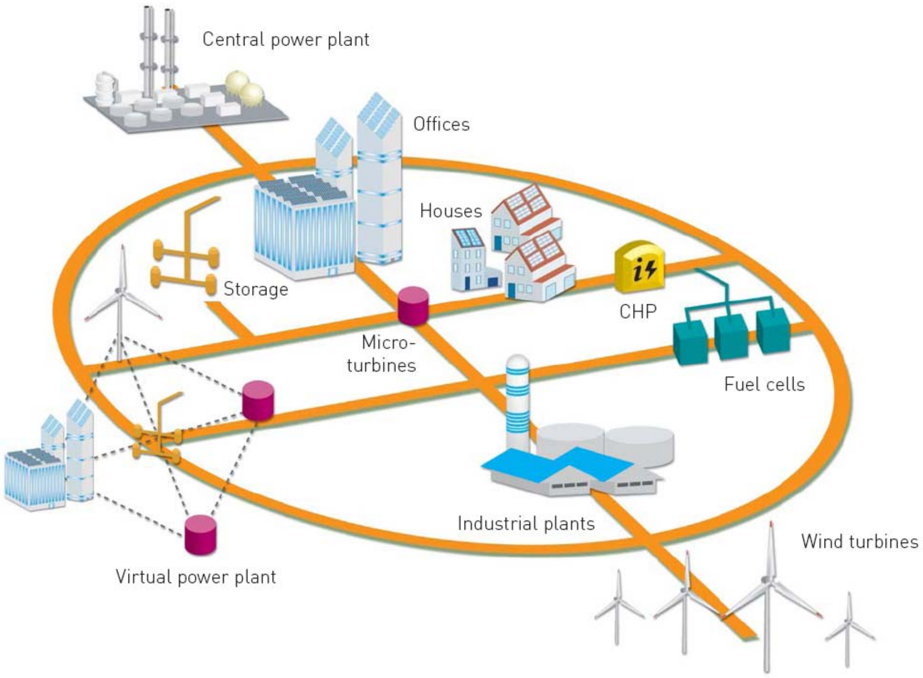


Figure 11. SmartGrids.

It is seen from these studies that the aim of the mentioned process is not just to improve the ability to incorporate fluctuating electricity sources but also to minimise the need for new costly interconnectors and – most of all – to improve the supply security in ‘open’ systems with many operators. There are two main headlines for this studies: a) more powerful communication networks. b) a change from AC distribution systems towards DC systems involving HVSC (high voltage semi conductors). The first can provide more flexible and efficient balancing of fluctuating electricity productions. The latter can provide cheaper and more effective transmission and distribution systems with less environmental impact (underground cables).

In Denmark, where the need for changes is big because of the high share of wind power, a large scale pilot test is ongoing with a new way of organising the distribution system – the cell system. It is described in detail in ref [6].

The idea is to equip a distribution area at the medium voltage level (60 kV) with an extensive information network connecting all producers and a number of large consumers. This will

create a semi-independent ‘cell’ where automatic balancing of as well active as reactive power can take place. In case of voltage break-downs at the higher levels of the transmission system this cell can disconnect itself and continue operation in ‘island’ mode. The cell is situated in the Holsted area in Southern Jutland and encompass as well wind turbines as CHP’s. [7]
Similar projects are under way in Australia and USA where a combination of new decentralised power plants (mainly N-gas combined cycle), high peak demands caused by air condition and a liberalised marked have caused a decreasing security of supply.[8]

CONCLUSION

A: The scenario calculations of the future electricity supply in different parts of Europe performed in the DESIRE project show that economic balancing of production and supply in the regions can only be achieved by carefully planning the combination of production units with different characteristica. A specific technology cannot be assessed alone, but only as part of a mix in a complete scenario analysis. The economy in establishing new transmission lines with the purpose of interregional balancing must also be analysed carefully as it depends strongly on the dynamic behaviour of the grids in the regions involved. Often such new transmission lines cannot compete economically with measures to improve the internal balancing potential of the regions involved. Part of the reason for this is the large costs and long planning periods involved in the strengthening of the internal transmission networks which are necessary to distribute the increased exports and imports.

B: Fundamental changes in the electricity production and distribution systems are taking place for the following main reasons:

- Development of cheaper and more effective information technology
- Development of more effective and flexible power transmission systems (DC)
- A need to incorporate larger shares of fluctuating and unpredictable electricity productions (RES) and combined-heat-and-power (CHP)
- A wish to open and liberalise the electricity markets

These developments are not in conflict. An example: The improved information systems which are needed to secure safe operation of decentralised production can also be used for advanced market functions. This can secure optimal allocation of production units and effective balancing of fluctuating productions.

REFERENCES

1. Homepage for DESIRE project, www.project-desire.org
2. Homepage for EnergyPLAN software, www.energyplan.eu
3. ExternE Externalities of Energy – Methodology annexes, Appendix V:Assessment of global Warming damages. EU commission, Brussels 2002.
4. IDA, Ingeniørforeningens Energiplan 2030, Copenhagen 2006. (The energy plan 2030 of the association of Danish engineers – in Danish.)
5. Rapport fra arbejdsgruppen om kraftvarme- og VE-elektricitet, Danish Energy Agency, Copenhagen 2001, (Report on CHP and RES electricity – in Danish).
6. Lund, P, Cherian, S and Ackermann, T, A CELL CONTROLLER FOR AUTONOMOUS OPERATION OF A 60 KV DISTRIBUTION AREA, *International Journal of Distributed Energy Resourses*, Vol. 2, No. 2, pp 83-100, 2006
7. Official planning report for 2006 for the Danish TSO, Energinet.dk
8. Platt, G, James, G P, Wall, J, West, S. The Intelligent Control of Distributed Energy Networks. *EIC2006.* CSIRO, Australia.

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Aikaterini Fragaki & David Toke, The University of Birmingham Anders N. Andersen, EMD International A/S
E-mail	d.toke@bham.ac.uk
Title of dissemination	Optimal Design of Combined Heat and Power Plants Using Thermal Stores in the UK
Type of activity	Article in peer-reviewed journal
Title of forum	Energy Conversion Management (Submitted)
Language	English
Date of dissemination	November 9th 2005
Place of dissemination	Europe
Brief abstract / description of dissemination activity	There has been discussion about the extent to which combined heat and power (CHP) plants with thermal stores are suitable for sustainable energy production and, under certain conditions, for integration of wind energy. At the moment, in the UK the development of this type of plant is limited. This paper analyses the economics and optimum size of (CHP) operating with gas engines and thermal stores in British market conditions assuming that all electricity is exported to the public electricity supply. This is achieved using energyPRO software. It is shown that, due to the big differences in electricity prices between day and night, the use of thermal stores could make the practice of exporting electricity from CHP plant much more profitable in the UK. The optimal size of CHP plant (exporting its electricity to the grid) for a district or community heating load of 20000 MWh per year is found to be a 3MWe gas engine with a 7.8 MWh thermal store. In this case the analysis reveals that the use of thermal store more than doubles the return on investments (as measured in net present value). It is concluded that thermal stores can improve the overall economics of CHP plants in present British circumstances.
Audience impact assessment	The article is awaiting peer review so the audience impact assessment is currently unavailable
Dissemination	Included after this form

Optimal Design of Combined Heat and Power Plants Using Thermal Stores in the UK:

Aikaterini Fragaki[a,*], Anders N. Andersen[b] , David Toke[c]
[a,c] The University of Birmingham, 32 Pritchatts Road ,Edgbaston, Birmingham B15 2TT
[c] EMD International A/S, Niels Jernes Vej 10, 9220 Aalborg, Denmark

Abstract

There has been discussion about the extent to which combined heat and power (CHP) plants with thermal stores are suitable for sustainable energy production and, under certain conditions, for integration of wind energy. At the moment, in the UK the development of this type of plants is limited. This paper analyses the economics and optimum size of (CHP) operating with gas engines and thermal stores in British market conditions assuming that all electricity is exported to the public electricity supply. This is achieved using energyPRO software. It is shown that the use of thermal stores could make the practice of exporting electricity from CHP plant much more profiatble in the UK. Hence this system can improve the overall economics of CHP in the UK. The optimal size of CHP plant (exporting its electricity to the grid) for a heat load of 20000 MWh per year is found to be a 3MWe gas engine with a 7.8 MWh thermal store. In this case the analysis reveals that the use of thermal store more than doubles the return on investments (as measured in net present value). It is concluded that thermal stores will make CHP plants more economic in present British circumstances; therefore, in the future CHP with thermal stores could potentially offer a flexible strategy to integrate fluctuating wind power production as is currently practiced in Denmark.

Keywords: CHP, Sustainable Energy, Thermal store, wind

[*] Corresponding author. Tel.: +44 121 041 47135; fax: +44 121 041 46061
E-mail address: a.fragaki@bham.ac.uk (A. Fragaki).

1. Introduction

Combined heat and power is the simultaneous production of electricity and heat. Combined heat and power plants (CHP) produce energy in an efficient way by decreasing the fuel consumption while producing the same amount of electricity and heat with the conventional generation, where electricity and heat are produced in separate plants[1,2]. For this reason, CHP and renewable energy sources are the focus of recent research on innovative concepts for sustainable energy production[3,4,5]. Furthermore, CHP technology can be combined with thermal stores which allow the CHP to generate electricity when power prices are high, and go offline when prices are low. They allow CHP plant to store heat when it is not needed, and they allow CHP plant to go offline because heat load can still be met from the stores. CHP plants with big thermal stores offer the possibility for integrating wind energy into the electricity network. This is an established practice for dealing with wind energy fluctuations in Denmark[6,7,8].

In the longer term, it is likely to be the case that there will be greater demand in the UK to seek the most cost-effective means of integrating fluctuating renewable energy production. The Government has a target of deriving 20 per cent of UK electricity from renewable energy by the year 2020. However, currently in the UK there are not enough CHP plants with thermal stores for wind energy integration[9]. Although work has been done to analyse the optimum economic size of thermal stores and CHP plant in other countries[10,11] and various optimization tool have been developed[12,13] little work has so far been done to analyse what the optimum sizes of plant and store are in the UK. However, there are widespread calls for more decentralised CHP in the UK and indeed there is a Government-backed demonstration programme, the community energy programme, to support such developments in the domestic and services sectors[14].

This paper investigates, using the energyPRO[15,16] software Excel spreadsheets the optimum design of CHP plants with thermal stores in the UK. This assumes recent UK conditions of heat demands, energy prices and plant performance and costs. energyPRO calculates the operation income of a selected plant configuration and Excel is used for the calculation of the Net Present Value (NPV) of the investments which is the criterion for the selection of the optimum plant configuration. Net present value is the discounted financial gain that is derived after various costs, including capital repayment costs, have been paid. A sensitivity analysis regarding the heat demand profile as well as the investment and operational and maintenance costs has also been conducted.

We carry out this study in the following order. We discuss how, in practical terms, CHP units can operate effectively with thermal stores. Then we discuss the workings of the energyPRO software which we use to analyse the most cost-effective sizes of gas engine CHP and thermal stores. We then describe out output-input-assumptions for the software model followed by the process by which we did the analysis with the software. We then discuss our results and come to a conclusion.

2. Background– Possible Use of CHP and thermal stores

In contrast to conventional power stations where the temperature of waste heat emitted is too low to make any use of it, in combined heat and power plants the heat from the engine is obtained while it is still at high temperature and it can thus be used for the production of industrial process steam or the heating of industrial and domestic premises, the so called district heating[2]. While the efficiency of the electricity production is thus reduced the overall thermal efficiency of the plant is significantly increased.

It has been observed, in Scandinavian studies, that the installation of a device for storing heat in CHP plant can be desirable on economic grounds. This heatstore is typically called thermal store or heat accumulator[17]. The thermal store is used for short term energy storage. It is a tank with a zone of hot water at the top and a zone of cold water at the bottom[18]. The two zones are separated due to the stratification effect with an approximately 1 metre high non-usable separation layer. The water content in the tank is constant in terms of weight and is independent of the energy content. When charging the thermal store hot water is supplied in the top of the tank simultaneously with extraction of the same amount of cold return water at the bottom. The process is reversed when discharging. The thermal store is connected to the district heating system between the CHP plant and the district heating network. When the heat production is higher that the heat consumption the thermal store is charged and it is discharged in the opposite case.

Thermal storage is a way of dealing with the mismatch between the electricity and heat demand. Typically, the electricity demand is high during morning and afternoon, lower during the rest hours of the daytime and even lower during nigh-time, weekends and holidays. This variation is reflected on the electricity prices, especially prices for exporting electricity to the public supply system.

Typically much electricity generated by CHP plant is consumed 'in-house'. A major problem in the UK is that electricity export prices have often not been high enough to justify generation by CHP plant for the purpose of exporting electricity to the grid. However, use of thermal stores may make this a more profitable exercise. This is a key focus of our investigations, and in order to simplify our model, we make our calculations assuming that all electricity is exported.

Consequently the prices of the produced or consumed electricity may vary significantly with the time of the day. The heat demand is usually low during the summer and higher during winter. The CHP is worth running when the electricity price is high. If the heat demand is low (e.g. summer daytime), the excess heat is stored in the thermal store. The stored heat can then be used when the electricity demand and therefore the electricity price are low and it is not economical to run the CHP (e.g. night-time). In other cases, the heat stored when the production exceeds the demand the heat can be used when the heat produced by the CHP is not enough to meet the heat load (e.g. winter). If there was no thermal store we would have to size the gas engine to meet the minimum heat demand or to stop or modulate the engine in order to avoid dumping the extra heat. Part load operation of the engine is undesirable because it reduces the engine efficiency. Large numbers of engine starts and stops has a significant negative effect on the performance and the lifetime of the engine[19]. Nevertheless the belief that gas engines are are able to start and stop with lower negative costs, in addition to their relatively low capital costs for small units, accounts for their widespread use in Denmark as the basis of CHP plant with thermal stores.

A further, interesting use of CHP plants with big thermal stores regarding sustainable energy production is for balancing the electricity production from renewable energy sources. This kind of operation presupposes that the CHP plants are decentralised CHP plants and therefore do not deliver frequency or voltage stabilization. This is the case in Denmark, where the wind penetration is high and the electricity production from wind turbines is sometimes as high as the electricity demand in the whole Denmark [6,7,8]: Decentralised CHP plants with thermal stores are at present being used, (indirectly, via the electricity spot market), to balance fluctuating wind energy output. The CHP plants might in the nearby future be widely used for offering system balancing for fluctuating wind energy outputs. The process is described briefly here.

In cases of a sudden increase in electricity production from the wind turbines, it is possible for the decentralised CHP plants to shut down some engines to reduce the amount of electricity produced. Due to the big thermal storage capacity the Danish CHP plants can still deliver heat. In other occasions, the wind turbines may fail to produce the expected amount of electricity. For example, they may have to shut down because of an approaching hurricane. As much as 1500MW[20] can then be obtained from CHP plants since their big thermal stores will be able to accommodate the excess heat produced simultaneously. Consequently large CHP and thermal storage capacities are required for this type of operation . This method of integrating fluctuating productions can be achieved if there is the possibility for CHP plants with thermal stores to aggregate and to act as a 'virtual big power plant'[1].

Clearly this concept presupposes that there exists an electricity market in the country which allows this type of aggregation. In addition there has to be a sufficient number of CHP plats with thermal stores, of the required size, to aggregate. The investigation of the market conditions in the UK that allow for the aggregation of the CHP units is beyond the scope of this study.

In the UK, at present, most of the CHP capacity is industrial CHP. Such plant does not normally have thermal store. In addition, industrial CHP plants deliver steam and therefore have to follow the steam demand which makes them inflexible and unsuitable for wind turbine integration in the utility network. Therefore, in the UK CHP plants suitable for the integration of wind energy have yet to be developed and as mentioned earlier, there are calls for the amount of non-industrial 'community' CHP to be built up. We define community CHP broadly as being CHP deployed in the non-industrial sector. The key difference with industrial CHP is that the bulk of the heat load is likely to be concerned with delivering heated water for heating, and other hot water requirements. This concern with delivering hot water means that thermal stores could be an important part of community CHP developments. Hence it is important to analyse the extent to which thermal stores could make such strategies of decentralised CHP more economic.

In order to assess the optimum sizes of engines and thermal stores and the improvement in plant economics, it is useful to conduct an analysis using variable electricity tariffs that are available in British electricity markets for exported electricity from CHP plant. This is what we do in this paper.

3. energyPRO

energyPRO[15,16] is an input/output software tool which is used for modelling energy systems. It can consider an unlimited amount of demands and energy units. energyPRO allows for changes in the modelled energy systems and the operation strategy in order to determine the optimal productions. In this work the energyPRO has been used for one year calculations. The input data that have to be specified for a study are the types of demands, like electricity, heat and cooling demands, the fuels, the specifications of energy units (production units and the thermal store) and the operation strategy. There is a decision table which is used to describe the priority amongst energy production units in all different specified periods of plant operation. In addition, the economy calculations should also be specified. There are several sorts of input data for the economy calculations depending on the nature of the study. In this work the input has been restricted to the revenues and the operating costs. The output includes the results of the calculations regarding the income from operation and the energy conversion. The latter refers to annually and monthly results of the energy productions, hours of operation, number of starts and fuel consumption of the production units.

The calculations in energyPRO are carried out, typically on hourly steps. However, instead of calculating the energy productions in a chronological order, the software calculates, productions of the most favourable periods for the whole year, as those are defined by the user. As a consequence, before being accepted, each new planned production is carefully checked sothat it will not disturb already planned productions with higher priorities.

The non-chronological operation is based on the concept of the division of the year in periods of priority. The prioritization is done according to the electricity prices most of the times. Then the operation strategy of the production units can be determined. As a result, in energyPRO the production is prioritised by the user according to the following argument: First production by the unit of the highest priority, one of the gas engines for example for the most favourable period, say the period with the highest electricity prices. This production is set by the user to have priority number 1. The second priority, priority number 2, corresponds again to a production unit and a period characterized by certain electricity tariffs. The rest of the priorities are established in a similar manner.

The software goes through the whole year six times for each priority number, performing the following loops[10,16]. In the first loop it tries to fill the production gaps. If for example a day had two periods characterised by high electricity prices, then an attempt is made by the software to keep the unit running during the intervening period . If not successful, all productions for these calculation periods in between will be inserted. In the third loop the production unit is forced to start in periods that they have the highest priority amongst the periods that they have not yet been calculated. This applies even if they are not neighbouring periods to those already calculated. In the forth loop, the production unit is forced to start when the fuel storage is full. In the fifth loop, the production unit is forced to start when the thermal store is empty. Finally in the sixth loop there is an attempt to produce during the periods that have not been examined yet, if there are any.

4. Input-Assumptions

The assumptions refer to the input data used in the energyPRO as well as the investments in the new equipment, gas engine(s) and thermal store and represent a generic case of current UK situation. The key technical assumptions are summarized in Table 1 and the key economical assumptions in Table 2.

Outdoor temperature

The outdoor temperature affects heat demand. Average daily data of outdoor temperature from Central England have been used in this study in order to consider the most general case. The data have been obtained from the energyPRO files (Test Reference Year).

Heat demand

The total heat demand was assumed to be 20,000MWh a year.

A typical heat demand profile has been assumed here[9] which is more representative of University campuses in the UK[9].

In the colder months, there are on a typical University campus a number of experiments that have to be kept warm at night, while the majority of units like teaching rooms, lecture theatres, offices, sports facilities, restaurants, would all have no requirement for heat during the night. Therefore a ratio of 2:1 daytime to night-time demand has been assumed.

Given that University campuses are usually compact, network losses are expected to be between 20% and 10%. The same percentages are expected for the summer heat demand for hot water, as there is only a small demand for hot water if there are no residential blocks on the site. Therefore, in overall, 25% of the heat demand is assumed here to be independent of the outdoor temperature, while the rest 75% of the total heat demand is assumed to be dependent linearly on ambient temperature between September and May inclusive. The reference temperature for the dependent demand is also required as input by software in order for the demand to be distributed after a simple degree-day method[16]. The reference temperature is the temperature below which room heating is initiated. For the UK the reference or the so called base temperature, is typically considered to be $15.5^{o}C$[21]. At this value of ambient temperature most UK buildings can heat themselves without the need for supplementary heating, due to the internal gains from occupants and equipment and the solar gains through the building fabric – walls and windows.

Gas engines

Gas engines of 2MW and 3MW have been considered to get total CHP capacities between 2 and 4 MW. The largest natural gas engines currently available in the UK market[22,23] are 3MW capacity. As indicative values of efficiency[22,23] for the gas engines, 38% electrical efficiency and 40% heat efficiency have been assumed, when the energy input is measured in gross calorific value (GCV). The engines in this study are assumed to have the same efficiency which is a good approximation given that they differ little in size.

It has also been assumed that the gas engine(s) is not available for 4 days twice a year either for maintenance purposes or due to grid failure. Due to the negative effects of starting and stopping the engine frequently, it is desirable to consider solutions with a reduced number of starts of the engines. To this end a restriction has been introduced, according to which the minimum operational time of the engine is set to two hours.

Boilers

In UK boiler plants typically run standard boilers[9,27] and the existing systems are not designed for the low temperatures required for the condensing boilers[24,25]. For this reason in the general case that is examined in this work a plant with standard boilers has been considered. However, it should be mentioned that recent regulations are pushing for higher efficiency in boilers[26].

Typical efficiency value of a standard natural gas boiler used in UK plants is 80% to 85% in gross calorific value for 2.5-3 MW boiler size[27,28]. It is common practice in applications to use more than one boiler of smaller capacities than one big boiler. In this way, firstly, there are always boilers available for operation in case one is out of order for maintenance purposes and secondly more control can be achieved on the resulting temperature since the change in the output by starting up a new boiler is small. The disadvantage is that increasing number of boilers will increase the operational and maintenance costs and therefore there is always a compromise to be made. According to the above arguments, it has been assumed that the plant consists of 3 boilers of 82% efficiency.

Fuel

The fuel used for the boilers and the gas engine is natural gas. The heat value of the natural gas[22] is 10.73 kWh/Nm^3 in gross calorific value.

The thermal store

The temperature difference in the thermal store is the difference between the hot zone of the thermal store and the cold zone at the bottom of the thermal store. This difference in the UK is 30^{o}C[9]. Part of the thermal storage is not used in daily operation. Therefore there is an effective used volume or net volume. The percentage of the net volume has been set to be 90% of the total volume of the thermal store. These settings allow the software to associate the volume of the thermal store with the heat capacity. For example, a 100m^3 thermal store has thermal storage capacity of 3.1 MWh.

Periods of priority

The year is divided in periods of priority which are set according to the electricity prices. Therefore, each period is characterized by a fixed electricity price.

Operation strategy

The production of the gas engine during the hours of the highest electricity prices is set to be the production of the highest priority (priority number 1). In the case of a plant with more than one gas engines both gas engines are set to have the same priority for production during a particular group of hours characterized by a certain electricity price. The gas boilers are prioritised after the gas engines.

The gas engine(s) is only allowed to operate at full load and it is allowed to produce heat in the thermal store. The boilers can operate either at full load or part load and they are not allowed to produce in the thermal store.

Revenues-expenditures

The revenues are from the heat and electricity sales. The expenditures are for the fuel used and the operational and maintenance costs of the gas engines and the boilers. The gas cost and electricity sale prices that are used in this study are approximate values indicative of costs observed in various UK applications for the years 2005-2006 and they do not refer to all particular applications. It is not possible to produce benchmarks to cover all applications although some data, such as operating costs, have been generated by some studies in a generic fashion which we cite elsewhere in this study.

For a boiler plant the cost of the gas includes the climate change levy (CCL). The CCL[29] is a tax which came into effect on the 1st of April 2001, and applies to energy used in the non-domestic sector, that is industry, commerce and the public administration sector. There are several exemptions from the levy in order to support energy efficiency schemes and renewable sources of energy. A boiler plant is not exempted from the CCL and has therefore to pay £1.5/MWh for the gas consumed.

In contrast to boiler plants, CHP schemes are exempted from the CCL on the energy use if they are assessed as being ‘good quality’[29,30] CHP. There are two key parameters for assessing a CHP scheme; the power efficiency and the Quality Index (QI). A scheme that qualifies as Good Quality CHP for its entire annual energy input is one where the power efficiency equals or exceeds 20%. The power efficiency is defined as the ratio of the total annual electricity output of the scheme to the total annual fuel energy input and it is based on the gross calorific value of input fuel. A scheme that qualifies as good quality CHP for its entire annual power output is one where the QI equals or exceeds 100. The Quality index of the plant is an indicator of the energy efficiency and the environmental performance of the scheme. It takes account of the fact that power supplied is more valuable than heat supplied[30].

energyPRO allows for the calculation of the QI of the plants.

In the cases of the CHP plants examined here the plant is always qualified for CLL exemption.

The price at which the plant sells the heat is assumed to be equal to the cost of producing 1kWh heat with the boilers. This cost includes the cost of the gas and the operational and maintenance costs of the boilers.

The electricity is sold at variable tariffs[9]. There is price variation during the day and during the year with high prices during the daytime and in winter and low prices during the night and during summer. The tariff profile considered in this work is applies to an example of plants with capacities 2.5 to 3.5 MW. We use this as the best data to hand, in the absence of representative data. The fact is that tariff profiles are, in any case, not publicly avialable. For reasons of commercial confidentiality we cannot publish our example in full, but we can give an idea of the range. Figure 1 shows a comparison between the highest peak and the lowest off peak electricity tariffs in February. 3.4 £/MWh has been added to the prices to account for incomes in respect of the CCL exemption that applies to electricity exported by CHP plant. This amount is 80% of 4.3 £/MWh, and is typical of the contract offer from electricity suppliers[29].

It should be noted that there is a minimum acceptable electricity price for a given gas price. This is the price at which the boiler and the gas engine are producing heat at the same price. At lower electricity prices the boilers are producing heat cheaper than the gas engine and in this case we should not run the gas engine. This minimum accepted electricity price has been calculated in our model to be £29.4/MWh_{el}. Similarly, there is a maximum electricity price for a given gas price, above which it is better to dump heat using a device like a cooling tower (if the thermal store is full). This maximum electricity price is equal to the cost of producing 1MWh electricity with the gas engine and it includes the cost of the consumed gas and the operational and maintenance cost of the engine. This price has been calculated to be £55.7/MWhel.

The operation and maintenance costs of the engines are assumed to be dependent on the size of the engine[22]. The operational and maintenance costs of the range of the engines considered here engines considered here are estimated to be within the range of £5.5 to £6.5 /MWh_{el} and these values can be considered representative of an average UK situation. The starting and stopping of the engine during the operation of the unit is done automatically and there is not additional cost involved.

Typical operational and maintenance costs[27] of 2.5-3 MW boilers are £250 per year for cleaning. In the case of larger boilers that require more time for cleaning the cost will be doubled. It will cost £500 per year to maintain the burners. In this study, there are three boilers in the plant, so the operation and maintenance cost of the boilers will be £2,500 per year.

Investments

As in the case of the operation and maintenance cost and the electricity prices the investment cost assumed in this application are typical UK costs.

The capital cost of one MW engine including installation and the additional equipment needed (heat exchangers, chimney etc) is 500,000 £/MW for 1MW engine and it is reduced for bigger engines[22].

The investment cost in the thermal store[9] is 714 £/m^3.

The lifetime of the investments is taken to be 15 years and the discount rate 5%.

These are used because they are common parameters for assessment of large scale energy projects in the UK financed through project finance[31]. Small companies may require more rapid rates of return, but there is some benefit in using parameters also used for large power projects since we can use the analysis to compare the economics of CHP with other power projects.

5. Methodology

The reference plant is assumed to be a natural gas boiler plant which covers the total annual heat demand. The various plant designs examined in this study are compared with this reference plant. The expenditures of the reference plant equal the revenues since it has been assumed that the heat is sold at a price equal to the production cost. It is assumed, in the first simulation with energyPRO, that this plant invests in a 2MW gas engine and a small, 1.6 MWh (50 m^3) thermal store. In the new plant, the production of gas engine will meet part of the heat demand, either directly, or indirectly, through the thermal store. The latter refers to the heat stored during the time of production to be used later on when the heat demand exceeds the production of the engine or when the engine is off.

The heat is sold at the same price as before and the electricity is sold at variable tariffs presented in section 4 of this paper under the heading ‘Revenues-Expenditures’.

The software calculates the annual income of the plant and this value is used as input in an Excel file to calculate the present value (PV) and the net present value (NPV) of the investments in the gas engine and thermal store. The net present value (NPV) is the present value minus the capital cost of the investments. So, as has been mentioned earlier, the net present value represents the net financial benefits derived from the project after taking into account the cost of the plant and after discounting the net income from the revenue stream.

The next step is to consider investment in the 2MW engine and larger sizes of thermal stores. The operation income is calculated each time in the energyPRO and the NPV of each alternative configuration in Excel. The optimum solution is the one that corresponds to the maximum NPV. The process is repeated for CHP sizes of 3 and 4MW. Hence we consider 1x2MW engine, 1x3MW engine and 2x2MW engines plant taking into account the availability of the gas engines in the UK as mentioned earlier.

A sensitivity analysis is carried out regarding the heat demand by comparing with a case study heat demand variation. The calculations, therefore, for the plant which runs only boilers in order to cover 20,000MW heat demand annually are repeated in the energyPRO for heat demand assumed to follow the same monthly variation with the heat demand[32] in the Kings Buildings CHP scheme in Edinburgh University. The daytime to night-time ratio is assumed to be the same with the heat demand of the general case[28].

The reference temperature was calculated from the monthly average values of the heat demand at the site and the monthly average temperatures of East Scotland obtained from the met office website[33]. The reference temperature was found 12.9^{o}C as opposed to 15.5^{o}C, which was the reference temperature assumed in the general case. Assuming 1.16MW constant hot water and network loss the fraction of the dependent demand was calculated to be 61%, which is smaller than the fraction assumed in the general case. Different alternatives of gas engine-and thermal store were investigated and the net present values of each investment were again calculated in Excel.

Further sensitivity analysis was carried out regarding the investment cost of the gas engines and thermal stores and the operational and maintenance costs of the gas engines. Danish figures[34] have been used for this analysis for comparison, since Denmark is leading in terms of integrating distributed production into the national electricity production system[8]. This correspond to 20% reduction in the investment cost of the gas engine, 72% reduction in the investment cost of the thermal store and in 18% reduction in the operational and maintenance costs of the engines. Prices like these might occur in a future UK market with a high dissemination of these systems.

6. Results and discussion

Figure 2 shows three curves representing CHP sizes between 2 and 4 MW. Each curve shows the NPV as a function of increased storage capacity. It can be seen that the NPV increases in the beginning by adding storage capacity and then falls as the cost of expanding the heat storage becomes higher than the benefit. The optimal design is the point of the curve that results in the highest NPV. The optimum investment in gas engine and thermal store for a plant which uses only boilers to meet 20000 MWh annual heat load is the investment in 1x3MW engine and 7.8 MWh (250m^3) thermal store. In this case the net present value was found to be £804,231 for the 15 years lifetime of investments and 5% discount rate. In addition, it has been found that the engine covers 85% of the annual heat demand in a year and runs 61% of the time. The optimum size of thermal store for the 2MW engine is 4.7MWh (150m^3) and the engine covers smaller percentage of annual heat demand, 67.7%, and runs fewer hours a year, 73.2%. The optimum size of thermal store for a 2x2 MW engine is 6.3 MWh (200m^3) and the engines cover larger amount of heat demand, 94.6%.

Clearly there are various combinations of engine sizes that give a total capacity of 2MW, 3MW or 4MW. The effect of the different combinations on the Net Present Value of the investment will depend on the efficiency and size relationship of the engines and the pricing mechanisms regarding the investment and operation and maintenance costs in relation to the engine size. The pricing policy assumed here favours the use of one large engine instead of more engines of smaller capacity. On the other hand the assumption that the efficiency is independent of the size of the engine favours the use of smaller engines instead of one big since smaller engines have lower efficiencies. Furthermore it can be seen that the bigger the engine the bigger becomes the optimum size of thermal store (e.g. the 3MW engine needs 7.8MWh thermal store for optimum operation while the 2MW needs 3.1). However, the use of several small engines instead of one bigger leads to smaller optimum storage size since, one of the small engines can operate during low heat demand with out the need of big thermal store. This is why the 3MW plant needs smaller thermal store for optimum operation than the 2X2MW plant.

It is important to note that the addition of thermal storage makes more larger CHP units more economic; e.g. without thermal store the 2MW CHP would be better investment than the 3MW (Figure 2).

It should also be noted that the addition of a thermal store makes a considerable improvement to the economic functioning of the CHP plant. As can be seen in Figure 2 without the thermal store the NPV of the 3MWe plant is less than £350,000 whilst if it works with the optimal size of thermal store the NPV is over £800, 000. Hence the (NPV) financial benefit of having the thermal store compared to not having the thermal store approaches half a million pounds And is more than doubled in size.

It has been commented that, because of the administrative changes brought in during the latest stages of electricity market liberalisation, the effective export tariffs available for small CHP plant have been lower compared to electricity prices on the main wholesale electricity markets[20]. This is essentially because they have to sell to third parties who discount the value of the electricity compared to what is available to power stations through power exchange trading.

It has been calculated that, were a regulatory reform introduced to give the same variable tariffs to small generators that is available through power exchanges, then income from electricity export sales would increase by around 30 per cent compared to the figures used in this study[20]**.** This would improve the economics of the use of thermal stores with gas engines still further.

It is useful to present how the CHP plants operate according to the input settings in the energyPRO. Figure 3 shows a production graph from the energyPRO of one week winter operation of the optimum plant. The upper curve shows the variation in the electricity tariffs. The next curve shows the heat productions of the gas engines and the boilers as well as the heat demand (heat consumption). The bottom curve gives the expected content of thermal energy in heat storage. It can be seen that the engine runs when the electricity prices are high while at night (when the prices are low), the engine may stop for some hours. In addition, it can be seen, that, the engine turns on only when it can operate continuously for at least two hours. When the engine(s) produces more than the heat demand then the extra heat is stored in the thermal store if there is space. When the engine is off, or when it does not produce enough heat to meet the demand, the heat from the thermal store is used in order to cover the heat demand. In case there is more heat needed, the boilers turn on to meet the demand. In detail:

On Monday at 00:00 the heat from the engine is not enough to meet the heat demand and the heat from the thermal store is used. At 6:00 the thermal store is completely empty and the boilers turn on to meet the demand that is not covered by the engine. The boilers are running until 21:00. After 21:00, the engine itself can cover the heat demand until the midnight. Then the heat demand drops and the engine produces more heat that is needed. As a result the thermal store starts to fill in. At a latter stage, on Wednesday at 00:00-02:00 that the engine is off the heat is provided only by the thermal store.

It is important to investigate the effect of the variable electricity tariffs on the optimization of the plant operation.

Without the variation in the electricity tariffs the operation of the CHP plant would be as shown in Figure 4. It should be noted that in Figure 4 the curve with the electricity tariffs has been omitted here because a fixed tariff is assumed:

The engine stops only when the thermal store is full, for example on Wednesday at 3:00. The engine starts again whenever it is possible to operate continuously for two hours-as it set in the input- without the need to dump heat. When this condition applies and the engine starts again to operate, the thermal store may be either completely empty, like, for example, on Wednesday at 7:00, or party empty, like, for example, on Sunday at 4:00. If this condition does not apply, and the thermal store is empty, it is the only case that the heat will be provided exclusively by the boilers.

Having prioritized the production according to variable electricity tariffs the above operation is modified as it can be seen in Figure 3. The engine does not stop only when the thermal store is full like on Tuesday at 00:00; it also stops when the thermal store is partly empty and further operation of the engine during the following hours is going to prevent its operation at a latter stage during hours of better electricity prices (higher priority). This is the case on Wednesday at 4:00, when the engine stops so that the operation is possible between 7:00-24:00 when the electricity prices are higher. The same principle, together with the requirement of the engine being able to run for at least two hours without the need to dump heat, determine when the engine turns on; if the engine should not turn on, and yet there is still a need for heat then the boilers start. It is possible in this case, that only the boilers are running while the gas engine is off and the thermal store empty, like for example on Friday 6:00-8:00. In this case, the operation of the boilers during the hours of low electricity tariffs allows for the operation on the engine during the consecutive hours 8:00-19:00.

Clearly the highest the difference in the electricity tariffs between day and night the most pronounced the benefit of using thermal storage.

In UK the development of CHP with gas engines is made more economic if it is done with thermal stores given that the variable rates of electricity tariffs apply. The reason is that the high difference of electricity tariffs between day and night makes it possible to take advantage of the thermal storage ability of the plant in order to exploit the high electricity rates during the day. It becomes more economic for the engine to run for a larger part of the year.

In the case of heat demand variation similar with that at Kings Blds in Edinburg, the optimum investment is a 1x3MW engine, that is the same size with the general case and 4.7 MWh (150 m^3) thermal store (Figure 5), as opposed to the larger thermal store of the general case. In addition the NPVs are higher for all engine and thermal store sizes compared to the general case. The reason for finding smaller thermal store as optimum investment, is, that the heat demand variation is smother between winter and summer than in the general case, with higher heat demand in summer and lower heat demand in winter, as shown in Figure 6. For the same reason the engine is running more hours during the year (65%) and covers higher percentage of the annual heat demand (91%) in the case of Kings Blds heat demand variation.

Now we will discuss the results from the sensitivity analysis regarding the investment costs in gas engines and thermal store as well as the operational and maintenance costs of the gas engines. Figure 7 shows the results of investment in 2x2MW gas engines and in a 3MW engine when the costs mentioned above are similar with those in Denmark. In this case, it is better to invest in larger gas engine capacity and a larger thermal store; the 2x2MW engine with 12.5MWh ($400m^3$) thermal store is shown to be a better investment.

The difference between the UK and Danish prices could be due to: the differences in the real purchasing power of the exchange; because there are many CHP plants with thermal stores in Denmark, or because costs of different installation needs are included in the pricing.

Further research is needed to show whether the optimum size of CHP plants that can be developed in the UK and has been identified in this study, is suitable for aggregated operation under the rules of the UK electricity markets, in order to be used for wind[35] integration.

7. Conclusions

It has been shown how the high variation in the electricity prices between day and night allow thermal stores to improve the economics of CHP plants in the UK. It has been shown how the thermal store can allow for the engine to operate as a priority during hours of high prices. It has been found that the optimum plant designed to cover most of an annual heat demand of 20,000MW, would consist of a 3MW engine and 7.8MWh ($250\ m^3$) thermal store. In this case the Net Present Value of the investment in the 3MW gas engine and 7.8MWh thermal store is improved by nearly half a million pounds compared to the case of not having a thermal store. A smaller thermal store is optimum if there is lower variation in the heat demand between winter and summer with higher summer and lower winder demand. In this case more fraction of the heat demand is covered by the gas engine and the NPVs are higher. Finally, it has been shown that investment and operation and maintenance costs as low as those in the Denmark would make a larger CHP plant a better investment. Further investigation should deal with the possibility of the optimum size CHP plants, which has been identified here, to aggregate in the UK electricity market in order to be used for integration of wind turbines.

Acknowledgements

The article is part of the EU-funded DESIRE project (Dissemination strategy on Electricity balancing for large Scale Integration of Renewable Energy).

We also acknowledge the assistance of PB Power in providing background technical and market advice on CHP operation in the UK.

References

[1] Andersen A.N., Lund H. New CHP partnerships offering balancing of fluctuating renewable electricity productions. Journal of cleaner production; 2006; in press.
[2] Rudig W. Combined Heat and Power for District Heating-An Anglo-German comparison of structural obstacles to the adoption of technology. Phys.Technol.; 1986;17: 125-131.
[3] Abu-Shark S. et al. Can microgrids make a major contribution to the UK energy supply? Renewable and Sustainable Energy Reviews; 2006; 10: 78-127.
[4] Alanne K., Saari A. Sustainable small-scale CHP technologies for buildings: the basis for multi-perspective decision making. Renewable and Sustainable Energy Reviews; October 2004; 8(5): 401-431.
[5] Onovwiona H.I., Ugursal V.I. Residential cogeneration systems: review of the current technology. Renewable and Sustainable Energy Reviews; October 2006; 10(5): 389-431.
[6] Akhmatov V. System stability of large wind power networks:A Danish study case. Electrical power and energy systems. 2006; 28: 48-57.
[7] Lund H., Munster E.. Modelling of energy systems with a high percentage of CHP and wind power. Renewable Energy; 2003; 28: 2179-2193.
[8] Lund H. Large scale integration of wind power into different energy systems. Energy; 2005; 30: 2402-2412.
[9]Interview with Paul Woods, James Eland and Dominic Cook from PB power, Birmingham 21-9-05.
[10] Lund H.,Andersen A.N. Optimal designs of small CHP plants in a market with fluctuating electricity prices. Energy Conversion and Management; 2005; 46: 893-904.
[11] Bogdan Z., Kopjar D. Improvement of the cogeneration plant economy by using heat accumulator. Energy; In press.
[12] Gustafsson SI, Karlsson BG. Heat accumulators in CHP networks. Energy Conversion Management; 1992; 33(12): 1051-61.
[13] Palsson OP, Ravn HF. Stochastic heat storage problem—solved by the progressive hedging algorithm. Energy Convers Manage; 1994;35(12):1157–71.
[14] http://www.est.org.uk/housingbuildings/communityenergy/
[15]Download Demo Version of energyPRO. www.emd.dk, 2006.
[16] Maeng H, AndersenKK, Andersen AN. energyPRO Users Guide. 2002.
[17] Gustafsson S.I. and Karlsson B.J. Heat accumulators in CHP networks. Institute of Technology; Energy Systems; Linköping, Sweden; 1992; S 581 83,
[18] Heat accumulators, News from DBDH 1-2004. www.dbdh.dk/pdf/production.html
[19] Haeseldonchx D., Peeters L., Helsen L. and D'haeseleer W. The impact of thermal storage on the operational behaviour of residential CHP facilities and the overall CO2 emissions. Renewable and Sustainable Energy Reviews; 2005; in press.
[20] Andersen A.N. et al. Organizational set-ups, optimizing tools and IT to be used in the DESIRE demonstrations, showing how CHP plants can participate in the integration of fluctuating productions from Wind Turbines. Version 1, 31-5-2006
[21] How and why to use degree day information, Carbon trust, 2004, ref:GIL135 www.thecarbontrust.co.uk/energy
[22] Interview with Mr Ian Hills, Clark Energy Ltd, UK, Runcorn, 3-2-06
[23]www.clarke-energy.co.uk, www.energ.co.uk, www.cogengo.co.uk,
[24] Section 4.3.1. Operating temperatures for hydronic systems in: CIBSE. Guide B1-Heating. CIBSE 2002.
[25] Section B1-13 and section B1-14 in: CIBSE. Guide B-Volume B. CIBSE 1986.
[26] ODPM Building Regulations. Part L-Conservation of Fuel and Power. 2006.
[27] Interview with Mr Clive Bannocks from YGNIS boiler suppliers, Birmingham, 6-12-05
[28] Interview with Dr David Somervell and Dr David Barratt from Edinburgh University, Edinburgh, 9-12-05
[29] Defra, UK, Climate change agreements, The climate change levy , 6 June 2005 www.defra.gov.uk/environment/ccl/intro.htm
[30] CHPQA. Quality Assurance for Combined Heat and Power. The CHPQA Standard. Issue 1. November 2000 www.chpqa.com/guidance_notes/documents/Standard_-_FINAL_VERSION.pdf
[31] Toke D. Are green electricity certificates the way forward for renewable energy? An evaluation of the UK's Renewables Obligation in the context of international comparisons. Environment and Planning C, 2005; 23 (3): 361-375.

[32] University of Edinburgh, King's Building Campus, Combined Heat & Power Benefit Report. Revision 2. Carl Bro; May 2005.
[33] Met Office, UK Climate and Weather Statistics www.met-office.gov.uk/climate/uk/2004/index.html
[34] Conversation with Anders N. Andersen

Figure captions

Figure 1 Comparison of highest peak and lowest off peak electricity tariffs in February
Figure 2 The optimum gas engine and thermal store size for a system that uses only boilers to generate 20,000MWh heat annually
Figure 3 Production graph from the energyPRO of the optimal plant configuration against the variable electricity tariffs
Figure 4 Production graph from the energyPRO of the optimal plant configuration against one fixed electricity tariff
Figure 5 Optimum gas engine and thermal store size for a system that uses only boilers to generate 20,000MWh heat annually when the heat demand varies in the same way with the heat demand in Kings Blds in Edinburgh University
Figure 6 Monthly average heat demand of the general case and the case of a heat demand that varies in the same way with the heat demand in Kings Blds in Edinburgh University
Figure 7 Optimum gas engine and thermal store size for a system that uses only boilers to generate 20,000MWh heat annually using Danish data

Temperature	• Daily temperature data of Central England
Heat demand	• Annual demand =20,000 MWh • 75% temp. dependent September to May • ref. temperature =15.5^o C • Daytime demand/Night-time demand =10/5
Gas engine (s)	• n_{el}=38% (GCV) • n_{heat}=40% (GCV)
Boilers	• n_{heat} =82% (GCV)
Fuel	• Natural gas • Heat value =10.73 kWh/Nm^3 (GCV)
Thermal store	• Temp difference=30^{o}C • Utilization=90%

Table 1 Technical input for the energyPRO calculations

Gas cost	18.9 £/MWh
Climate Change Levy (CCL)	1.5 £/MWh
Engine(s) O&M costs	~6-7 £/MWh
Boilers annual O&M costs	£2,500
Heat sale price	25 £/MWh
Electricity sale price	Variable tariffs
Investment cost of 1MW engine	£ 500,000
Investment cost of thermal store	714 £/m^3
Lifetime of the investments	15 years
Discount rate	5%

Table 2 Economical input for the energyPRO and Excel calculations

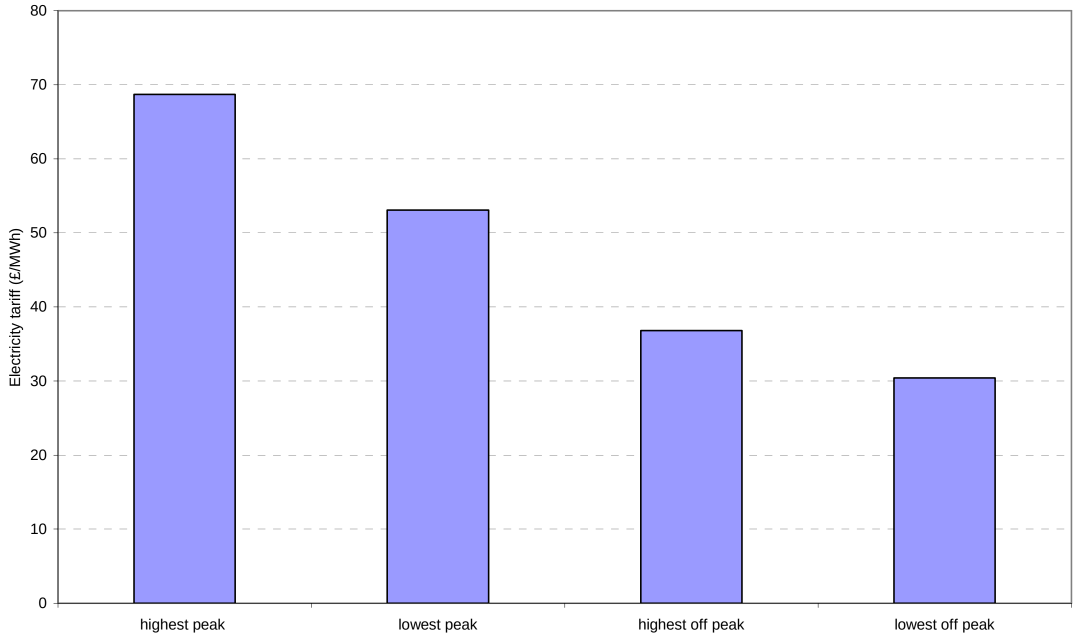

80
70
60
50
40
30
20
10
0
Electricity tariff (£/MWh)
highest peak
lowest peak
highest off peak
lowest off peak

Figure 1

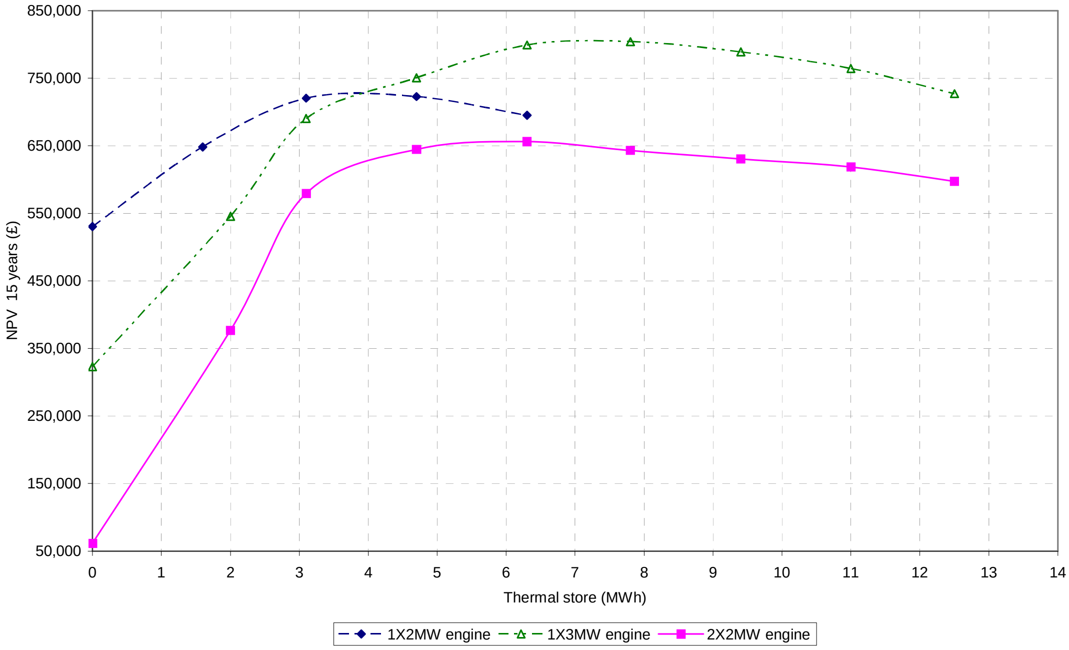

850,000
750,000
650,000
550,000
450,000
350,000
250,000
150,000
50,000
NPV 15 years (£)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Thermal store (MWh)
1X2MW engine
1X3MW engine
2X2MW engine

Figure 2

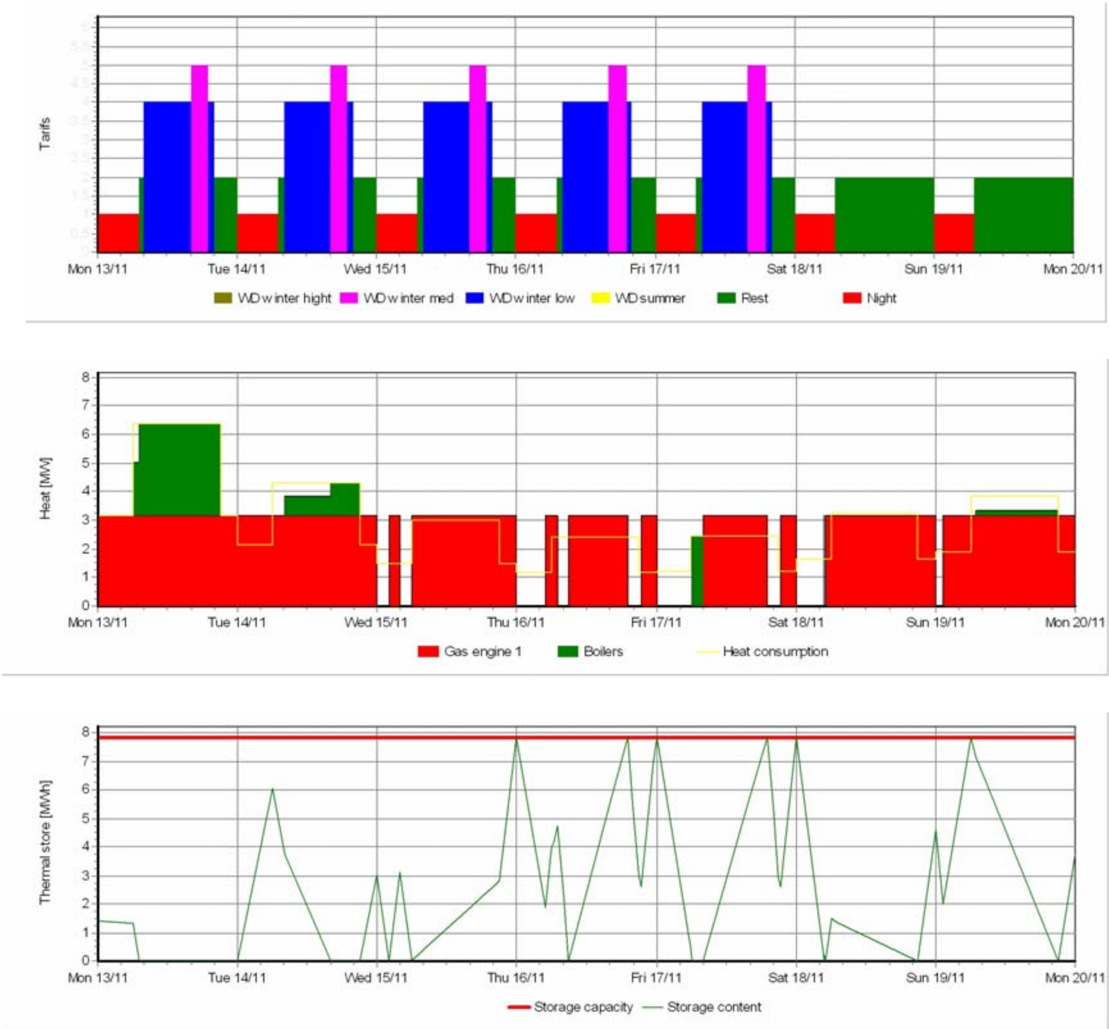
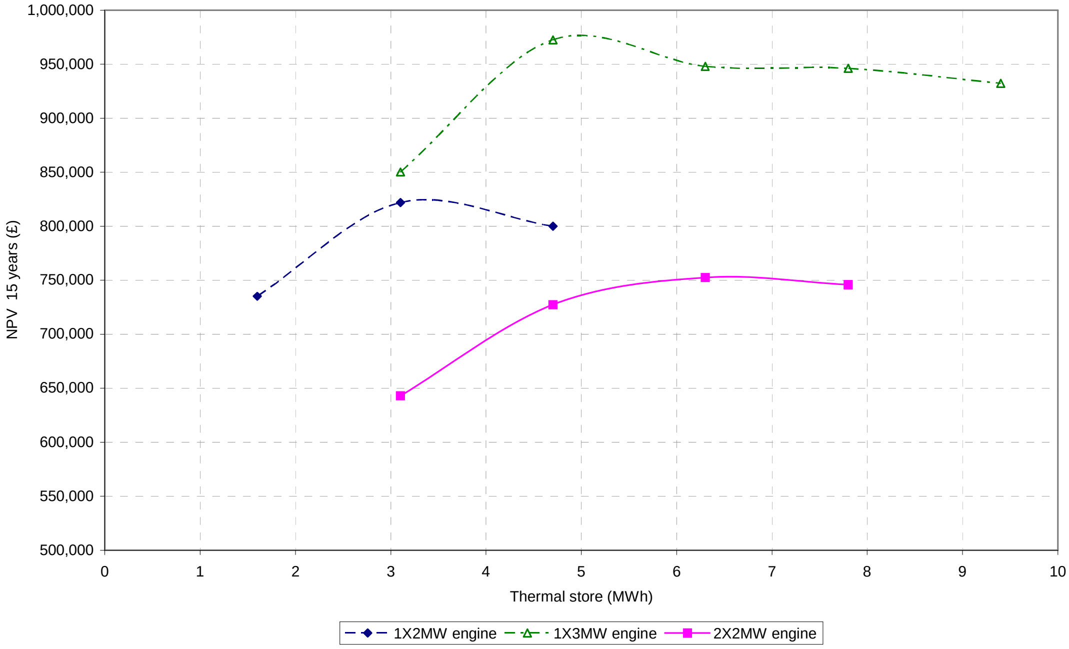

Tarifs
Mon 13/11
Tue 14/11
Wed 15/11
Thu 16/11
Fri 17/11
Sat 18/11
Sun 19/11
Mon 20/11
WD winter hight
WD winter med
WD winter low
WD summer
Rest
Night
Heat [MW]
8
7
6
5
4
3
2
1
0
Gas engine 1
Boilers
Heat consumption
Thermal store [MWh]
Storage capacity
Storage content

Figure 3


Heat [MW]
Mon 13/11
Tue 14/11
Wed 15/11
Thu 16/11
Fri 17/11
Sat 18/11
Sun 19/11
Gas engine 1
Boilers
Heat consumption
Thermal store [MWh]
Storage capacity
Storage content

Figure 4



1,000,000
950,000
900,000
850,000
800,000
750,000
700,000
650,000
600,000
550,000
500,000
NPV 15 years (£)
0
1
2
3
4
5
6
7
8
9
10
Thermal store (MWh)
1X2MW engine
1X3MW engine
2X2MW engine

Figure 5

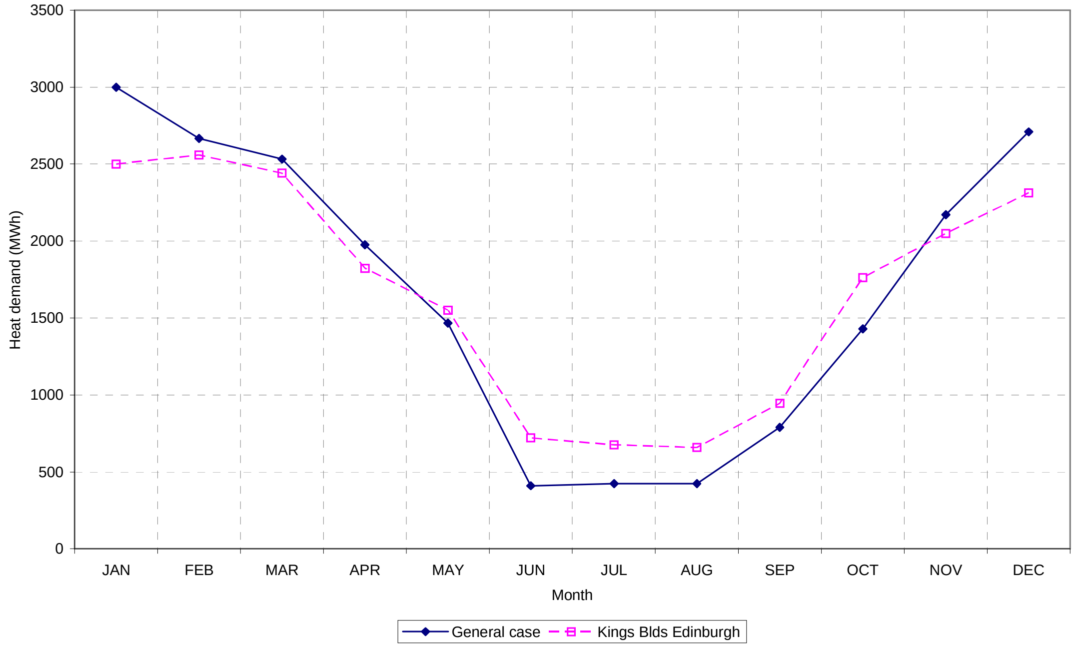

Heat demand (MWh)
3500
3000
2500
2000
1500
1000
500
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
General case
Kings Blds Edinburgh

Figure 6

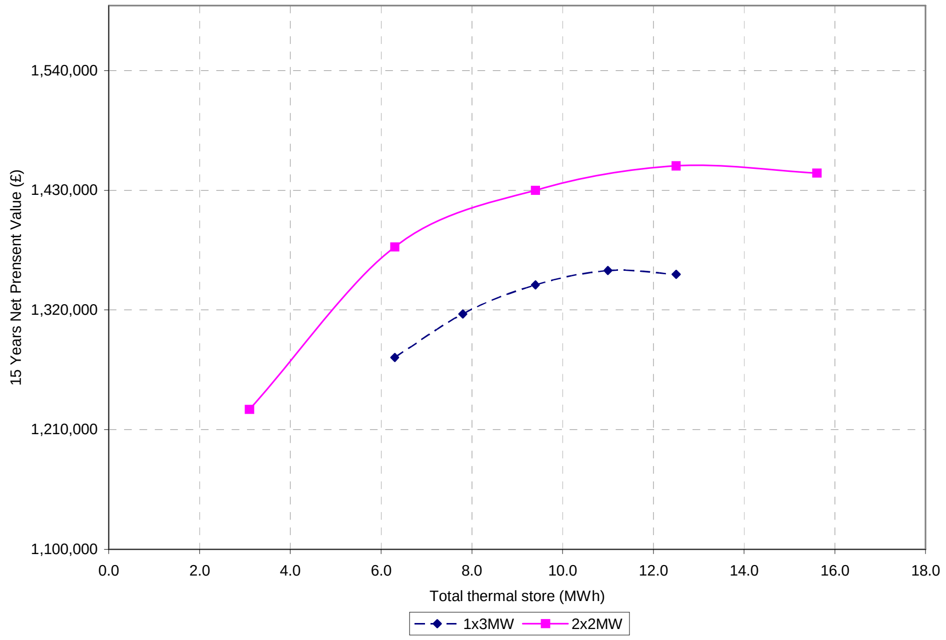

1,540,000
1,430,000
1,320,000
1,210,000
1,100,000
15 Years Net Prensent Value (£)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
Total thermal store (MWh)
1x3MW
2x2MW

Figure 7

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	David Toke, Katerina Fragaki, University of Birmingham
E-mail	d.toke@bham.ac.uk
Title of dissemination	DESIRE UK – Summary of Interim Research Conclusions
Type of activity	Article
Title of forum	Article to various stakeholders
Language	English
Date of dissemination	From October 2006 onwards
Place of dissemination	United Kingdom
Brief abstract / description of dissemination activity	The economic performance of community (and some industrial) CHP will be considerably increased by the use of thermal stores. Our modelling suggests that the optimum economic size in MWe is increased by over 50 per cent for a given example. Moreover, if, in addition to this, CHP units are 'aggregated' together to sell power to the grid, the economic performance of the CHP units will be further enhanced, and the optimum size of CHP plant increased by even greater amounts. This activity depends on the use of the thermal store system to sell exported power directly to wholesale power markets through aggregated despatch. Moreover, recent changes in planning policy guidance and incentives inherent in new building regulations create great potential for development of community heating and CHP in new building developments.
Audience impact assessment	The information has resulted in enquiries received on the nature of CHP with thermal stores and the possibilities for aggregating exports from CHP units using this system
Dissemination	Included after this form

DESIRE UK – Summary of Interim Research Conclusions

By Dr David Toke[i] and Dr Katerina Fragaki[ii], University of Birmingham

Abstract

The economic performance of community (and some industrial) CHP will be considerably increased by the use of thermal stores. Our modelling suggests that the optimum economic size in MWe is increased by over 50 per cent for a given example. Moreover, if, in addition to this, CHP units are 'aggregated' together to sell power to the grid, the economic performance of the CHP units will be further enhanced, and the optimum size of CHP plant increased by even greater amounts. This activity depends on the use of the thermal store system to sell exported power directly to wholesale power markets through aggregated despatch. Regulatory changes to establish a right for CHP plant to receive the same levels of payment for exported electricity as large power stations could also reduce penalties that are effectively imposed on small generators by BETTA. However, we see no regulatory barriers in the way of use of 'aggregated despatch' by CHP with thermal stores. Work still needs to be done to investigate and disseminate information concerning this proposed practice of 'aggregation'.

Moreover, recent changes in planning policy guidance and incentives inherent in new building regulations create great potential for development of community heating and CHP in new building developments. Action at a local government level is necessary to realise this potential. In the long term the thermal store-gas engine-CHP system, which is extensively used in Denmark, offers a flexible option for the integration of high levels of fluctuating renewable electricity into the grid. We shall be conducting further modelling over the next few months in order to analyse and develop 'best practice' arrangements for CHP and thermal stores.

Use of thermal stores

The thermal store is used for short term energy storage. It is a tank with a zone of hot water at the top and a zone of cold water at the bottom. In the UK thermal stores can, in the short term, dramatically improve the economics of community CHP. Here we use the term 'community CHP' to mean CHP acting as primary heat source in a community heating network. In the long term community CHP using thermal stores can present a flexible means of absorbing the output of fluctuating renewable energy sources into the grid, so expanding the economic potential for supplying renewable energy.

In Denmark, decentralised CHP units consist of highly efficient gas engines and use of thermal stores. These CHP plant supply around a quarter of Danish electricity and together all CHP plant supply over half of Danish electricity (with wind power

[i] Dr David Toke, e mail d.toke@bham.ac.uk, tel 0121 415 8616
[ii] Dr Katerina Fragaki, e mail Fragakia@bham.ac.uk, tel 0121 414 7135

supplying around 20 per cent). A large plant is set up by stringing several gas engines together in modular form. This has advantages compared to gas turbine technology at sizes under around 100MWe because of relatively low capital costs, higher efficiencies, and greater ability to work in 'flexible' as opposed to continuous operating modes.

In the UK, as in Denmark, thermal stores can allow CHP plant to produce electricity when electricity market prices are high, and shut off production of electricity when prices are low. When electricity prices are high, the heat generated by the CHP unit can be stored in the thermal stores (sometimes called accumulators) when it is not needed on site. When electricity prices are low, the CHP unit can stop generating and still service its heat demand from the thermal stores.

We have modelled the economics of CHP with and without thermal stores using a typical heatload. If we assume that all electricity is exported outside the plant then, the optimum economic size of the plant for heating load of 20,000 MWh per year is a 3MWe engine and a 250m3 (7.8MWh) thermal store. If there is no thermal store then the optimum economic size of the plant will less than 2 MWe. This is shown in Figure 1 in the Appendix. We used typical contract prices for gas and electricity revenue and expenditure to derive this result. We should note that most of the existing community CHP plants in the UK do not typically have thermal stores, are very small, and are sized to meet the minimum heat load so that the engine can run without wasting heat. We plan to carry out further modelling of CHP and thermal stores. This will involve refining our general model, and, in addition, we shall use operating data from three existing CHP plant that employ thermal stores in order to examine the optimal theoretical sizes of engines and thermal stores in these cases.

Incentives

Our overall conclusion here is that the current incentives available for CHP relative to conventional power stations are more than negated by the penalties imposed on small generators by the BETTA system.

The main incentive for CHP is the long term cost savings, but this is aided by the climate change levy (CCL) exemption. This involves CHP plant being exempt from paying CCL on gas consumed by the CHP facility and the and electricity that is exported. We modelled the impact of this in a typical UK CHP scheme assuming that it just covers its in-house electricity needs with the electricity produced. We found that for 2005 gas and electricity prices, it costs 34% less to run the CHP compared to a plant that has only boilers (operational and maintenance costs not taken into account). This percentage would be 27% if there was no CCL exemption. In addition to this the enhanced capital allowance and the business rates discount will give net benefits of the equivalent of around 5 per cent of CHP capital costs. However, we also have to bear in mind that a high proportion of CHP plant are currently in energy intensive sectors who in any case enjoy an 80 per cent reduction in liability for the CCL. This effectively reduces the value of the CCL exemption for CHP plant.

We must also take into account the most recent rounds of electricity market reforms, and these, in practice, work to considerably reduce the income of CHP plant and discourage them from exporting electricity. This occurs because all plant that trade on the electricity wholesale markets must comply with the terms of the balancing and settlement code (BSC). The administrative work required to do this, in addition to the fear of penalties that may follow defaulting on pre-announced output, dissuades CHP plant under 50 MWe from complying with BSC.

There is a common belief that 'consolidator' services, through which 'consolidator' companies buy power from several small plant and pool the output (treating them as negative demand), overcome the aforementioned problem. We do not doubt that consolidators generally increase income for CHP compared to the 'in house' electricity supplier, but our research suggests that the CHP plant still lose money compared to the prices large power stations receive for their electricity sales on the wholesale market. Analysis of typical examples used in our research suggests that **even using consolidator services, small (say 3 MWe), CHP plant will lose around a quarter of their income for exported electricity compared to the value of electricity sold by conventional power stations to power exchange markets**.

We have modelled the optimum economic size for a 'typical' community CHP plant using electricity export prices similar to that earned by large power stations. As can be seen in Figure 2 in the Appendix, if CHP plant export their electricity and use thermal stores and are paid the same for electricity as conventional power stations then the optimum economic size of the CHP plant increases considerably. This increase in size is from 3 MWe to between 4 and 6MWe in the case of CHP plant using thermal stores. Under current conditions of lower export prices and without a thermal store the optimum economic size is less than 2 MWe.

Hence the benefits derived from the CCL exemption and other incentives are likely to be outweighed by the fact that small CHP plant are unable to derive the same levels of income from exported electricity compared to conventional power stations. An additional problem, which has been highlighted by the Combined Heat and Power Association, and others, is that distribution network operators have a reputation of being uncooperative in connecting CHP units with nearby customers. This problem persists despite pilot schemes designed to alleviate this problem.

So how can we encourage CHP and community heating to be deployed in practice? One means is by taking advantage of recent changes in the planning environment. Further measures have been implied by our foregoing research conclusions; the development of CHP plant with thermal stores and also mechanisms to enable small CHP to earn the same levels of income for their exported electricity as earned by conventional power stations. We now turn to consider these various methods of bringing community CHP to market.

Bringing Community CHP to market

Two recent policy changes introduced by the Government have greatly enhanced the possibilities for community heating and CHP. First, Planning Policy Statement 1 (PPS 1) promotes CHP and community heating in new buildings. Second, the 2006 building regulations (Pat l) say that buildings must achieve 20 per cent greater carbon reduction compared to the 2002 building standards. Effective use of the PPS1 provision is patchy so far, but in parts of London spatial development planning is now at the stage where there is insistence that new housing developments must use community heating. CHP is incentivised through the new building regulations. Certainly, activity by NGOs and others to pressure local authorities and educate planning officers and engineers to adopt community heating and CHP will encourage more rapid proliferation of developments. If community CHP is in place in new building developments , and if PPS 1 and the new building regulations are properly enforced, then gas engine CHP using thermal stores can be introduced as a very cost-effective means of meeting the carbon reduction requirements in the revised building regulations..

Currently a very small number (around 5) examples of community CHP using thermal stores exist in the UK. Nevertheless a small number of companies with the expertise do exist to implement this technology, and a number of projects are in the pipeline. **It would be beneficial if case studies of existing schemes and those which are in the planning stages could be prepared and publicised among engineers and planners in local government, commerce and industry.**

Aggregated despatch

Aggregated despatch may allow CHP schemes to gain access to higher electricity prices than is practically possible at the moment. Note: this needs to be sharply distinguished from 'consolidation' where CHP power is aggregated as negative demand. By contrast aggregated despatch involves CHP plant acting together to sell electricity directly to one or other of the wholesale power markets. This would involve CHP plant with thermal stores being co-ordinated (as they are in Denmark) to act as 'big' power stations so as to generate electricity when there are peak power prices available.

When there is a critical initial mass of community CHP with heat stores (say 50 MWe) then full scale 'aggregated despatch' can be achieved. We see no reasons, in principle, why this should not be possible within the context of the present Balancing and Settlement Code. However, demonstrations will need to be conducted to investigate the adequacy of current regulatory arrangements.

Regulatory reform

A regulatory reform agenda could include a measure ensuring that all decentralised power generation (including, perhaps, microgeneration as well as CHP) receives the same sort of payments for electricity exports as conventional power stations receive on the power exchange markets. Such a regulatory reform would bring the UK in line with the EU Electricity Directive 2003/54/EC which proscribes electricity market balancing arrangements which discriminate against particular generators. For example, it is stated:

7. Rules adopted by transmission system operators for balancing the electricity system shall be objective, transparent and non-discriminatory, including rules for the charging of system users of their networks for energy imbalance. Terms and conditions, including rules and tariffs, for the provision of such services by transmission system operators shall be established pursuant to a methodology *compatible with Article 23(2) in a non-discriminatory and cost-reflective way and shall be published.*

In addition to this, regulatory reform is also required to establish transparent, effective rights for small generators to be connected to the distribution network. In general we believe that a ‘rights based’ approach to affording equal payments for electricity exports compared to conventional power stations and also easy grid and distribution connection is a necessary step.

The long term picture – absorbing more renewables

A key long term advantage of having a significant proportion of electricity generated from CHP with thermal stores is that this will reduce the costs of integrating high levels of fluctuating renewable energy sources into the grid. Community CHP is designed to be a flexible mode of generation, responding to changes in demand. Gas engine CHP organised in collaboration with thermal stores allow generation to be started and stopped with minimal losses in efficiency and maintenance problems compared to large conventional power stations.

The existence of large amounts of CHP with thermal stores will allow very large amounts of renewable energy to be absorbed into the grid without increasing economic penalties. This is because CHP with thermal stores are designed, as a system, to come on- and off-line in response to price changes. This flexible system is already being used in Denmark to integrate their large amounts of wind power into the grid, and it is likely to be used more in the future as the proportion of electricity generated from renewable sources increases beyond the present 20 per cent.

This lack of power stations flexibility will not be a problem at relatively low loads of renewables penetration (up to around 20 per cent). However, if, in the long term, the UK wishes to increase the proportion of renewables beyond 20 per cent and at the same time reduce the increasing costs of integrating such amounts, then it will be helpful to have a significant volume of production generated from gas-engine CHP with thermal stores.

The DESIRE Project is funded by the EU’s FP6 Programme. It is a consortium consisting of research and commercial institutions drawn from Denmark, Germany, UK, Spain, Poland and Estonia. DESIRE stands for Dissemination strategy for balancing for large scale integration of renewable energy. We acknowledge the information and advice from our sub-contractors, PB Power. This input has been invaluable to the project.

APPENDIX

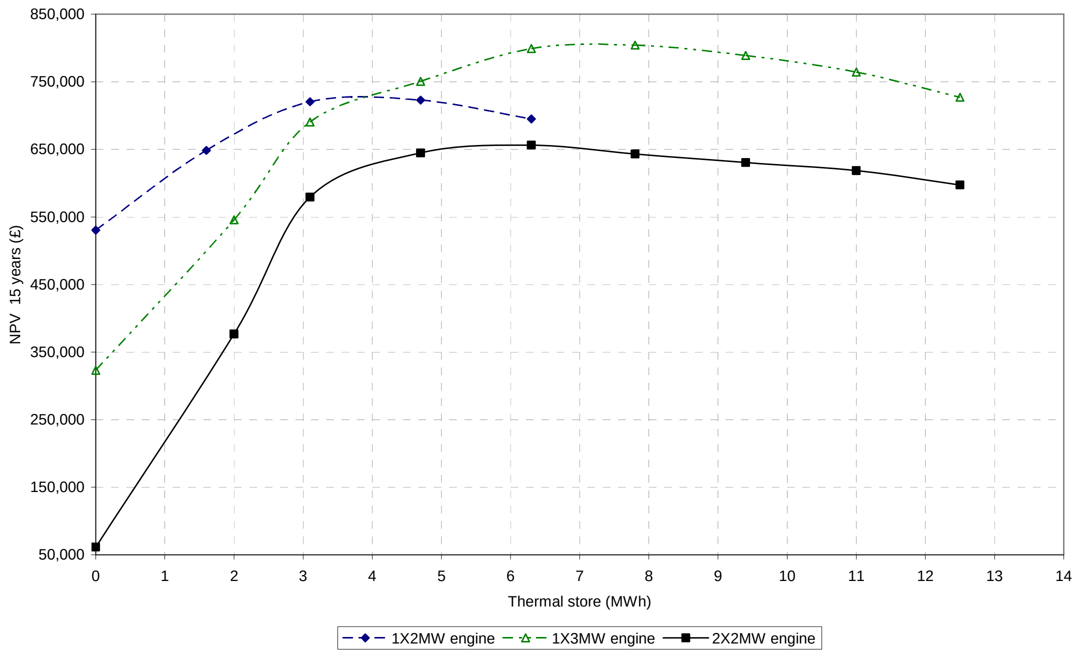


Figure 1: Thermal store optimization study for the UK, using typical **export electricity prices (September 2005-August 2006).**

The optimum plant for a district or community heating load of 20000 MWh per year seems to be a 3MW plant with (7.8MWh or 250m^3) thermal store. The Net Present Value of a 15 years investment assuming 5% discount rate is £ 804,231. **The pay back time is 6.9 years**.

NOTE: **without thermal store, the pay back time for this engine size is 8.4 years,** and the Net Present Value is £323,042.

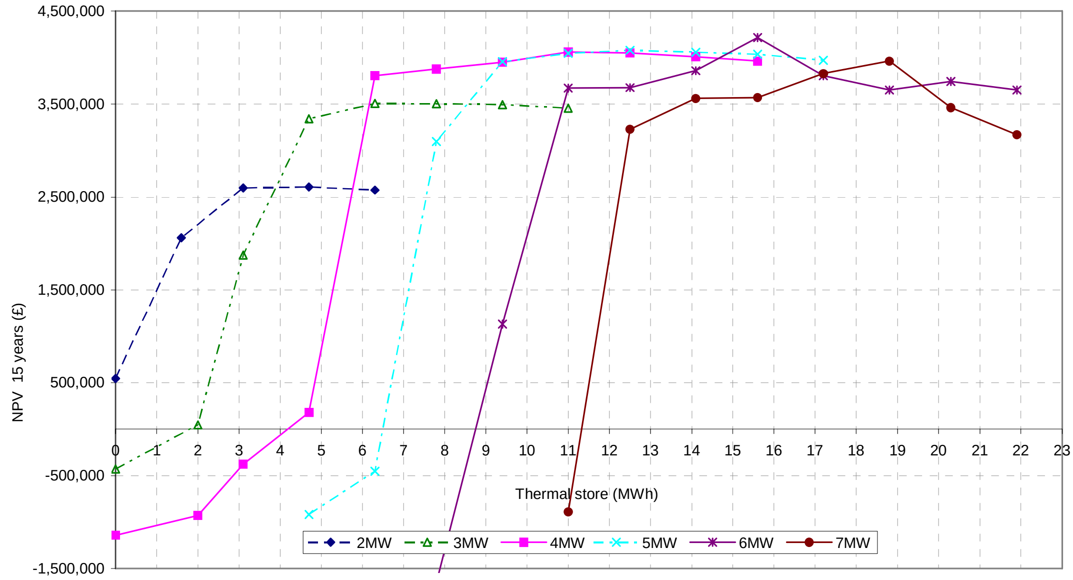


Figure 2: Thermal store optimization study for the UK, using **SBPs (July 2005-June 2006),** as a proxy for the system power exchange prices

The optimum plant for a district or community heating load of 20000 MWh per year seems to be a 6MW plant with 15.6 MWh (or 500m^3) thermal store. The Net Present Value of a 15 years investment assuming 5% discount rate is £ 4,216,324. **The pay back time is 4 years**.

END

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Aikaterini Fragaki, Richard Green, David Toke, University of Birmingham
E-mail	d.toke@bham.ac.uk
Title of dissemination	Incentives for CHP Development in the UK
Type of activity	Article in peer-reviewed journal
Title of forum	Energy Policy (Submitted)
Language	English
Date of dissemination	9th November 2005
Place of dissemination	International journal publication
Brief abstract / description of dissemination activity	This will disseminate information concerning incentives available to CHP in the UK compared to other countries. This article assesses the impact of the UK government's measures to promote CHP schemes, the most important of which is exemption from the Climate Change Levy (CCL), in support of its target for 2010 of 10,000 MWe of CHP generating capacity. This paper analyses the effectiveness of this exemption in terms of its impact on key investment parameters. It is shown that CCL exemption can reduce quite significantly the simple pay back period for a CHP project and has higher impact on the IRR compared to an accelerated depreciation policy.
Audience impact assessment	This is a high quality highly cited journal, so the message will be widely disseminated
Dissemination	Included after this form

Incentives for CHP Development in the UK:

Analysis and evaluation of their relative importance

Aikaterini Fragaki, Richard Green, David Toke

University of Birmingham

Edgbaston

Birmingham

B15 2TT

UK

February 2007

ABSTRACT

This paper assesses the impact of the UK government's measures to promote CHP schemes, the most important of which is exemption from the Climate Change Levy (CCL), in support of its target for 2010 of 10,000 MWe of CHP generating capacity. This paper analyses the effectiveness of this exemption in terms of its impact on key investment parameters. The annual cost savings in gas and electricity due to the CCL exemption are calculated for different energy prices and the savings are compared with the up-front cost of installing a CHP unit. It is shown that CCL exemption can reduce quite significantly the simple pay back period for a CHP project and has higher impact on the IRR compared to an accelerated depreciation policy. Exemption from business rates has little impact on the scheme's profitability. The benefits of exemption from the (fixed) CCL are proportionately least important when energy prices are high, but this is when support is least likely to be required.

Keywords

Climate Change Levy (CCL), Combined Heat and Power (CHP), financial incentives

1. INTRODUCTION

Combined heat and power (CHP) plants simultaneously produce electricity and heat. While the efficiency of the electricity production is reduced compared to the conventional power generation the overall thermal efficiency of the plant is significantly increased. The UK government has a target for 2010 of 10,000 MWe of

CHP generating capacity. To help reach this target, it has provided incentives in the form of Enhanced Capital Allowances that can be offset against Corporation Tax on profits, reductions in the Business Rates paid to support local government, and exemption from the Climate Change Levy (CCL) introduced as an environmental tax on energy use in 2001. This paper analyses the effectiveness of the CCL exemption as an incentive for CHP schemes.

The majority of the CHP schemes in the UK, about 12,000 schemes, are below 1MW electricity output. Most plants in the UK are sized to meet the minimum heat load on their site. Only a few have a device called a thermal store or heat accumulator[1] which allows for short term heat storage and is a way of dealing with the mismatch between the electricity and heat demand. The store is charged when heat production is higher than heat consumption and discharged in the opposite case. The gas engine plants usually have only one engine which is running full load 50% to 60% of the total hours in a year. The extra heat load above the minimum is met usually by one or two boilers. Typically, these plants do not produce more electricity that they need on site while sometimes they may have to buy electricity to cover the demand.

The Government announced, in 2000, a target of achieving at least 10,000 MWe of Good Quality CHP capacity by 2010 and the development of a Strategy to achieve it. A draft Strategy was published for consultation in May 2002 and in February 2003 the Energy White Paper – *Our energy future – creating a low carbon economy* – reaffirmed the Government's commitment to the target[2].

Currently the UK legislation provides three main incentives for CHP; the climate change levy (CCL) exemption, the enhanced capital allowances (ECA) and business rates reductions. This paper analyses and evaluates the impact of these incentives on a typical CHP scheme. It shows their impact on the simple-payback period and internal rate of return for the scheme, calculated for different prices for gas and electricity. It also calculates the break-even combinations of gas and electricity prices required to earn a given internal rate of return, and investigates how these vary with the level of incentives.

2. BACKGROUND

The CCL[3] is a tax which came into effect on the 1st of April 2001, and applies to energy used in the non-domestic sector, that is, industry, commerce and the public administration sector. There are several exemptions from the levy in order to support energy efficiency schemes and renewable sources of energy.

CHP schemes are exempted from the CCL on their energy use if they are assessed as being ‘good quality’[4] CHP. There are two key parameters for assessing a CHP scheme; the power efficiency and the Quality Index (QI). A scheme that qualifies as Good Quality CHP for its entire annual energy input is one where the power efficiency equals or exceeds 20%. The power efficiency (n_{power}) is defined as the ratio of the total annual electricity output of the scheme to the total annual fuel energy input, based on the gross calorific value of input fuel.[5] A scheme that qualifies as Good Quality CHP for its entire annual power output is one where the QI equals or exceeds 100. The Quality Index of the plant is an indicator of the energy efficiency and the environmental performance of the scheme. It takes account of the fact that power supplied is more valuable than heat supplied.

The general form of the QI definition is:

$$QI=(X*n_{power}) + (Y*n_{heat})$$

where X and Y are coefficients that are related to alternative power supply and alternative heat supply options in correspondence and their values vary for different sizes and types of CHP schemes

n_{power} is the power efficiency of the scheme defined as mentioned above and,

n_{heat} is the heat efficiency of the scheme defined as the ratio of the total annual heat output of the scheme to the total annual fuel energy input

The other legislative incentives are the ECAs and the Business Rates. The ECAs[6] were introduced for the first time with the Capital Allowances Act 2001, Section 45A(1) to (4). Corporation tax is charged at a rate of 30% on profits, but a business can write off the costs of capital investment against its profits over four years, effectively getting a tax rebate equal to 7.5% of the cost of the asset in each year. Accelerated depreciation allows the business to claim this rebate earlier, thus increasing the discounted value of the saving. A business can claim 100% first-year allowances (FYAs) if it incurs qualifying expenditure on designated energy-saving plant and machinery. This means that it gets a 30% rebate in the first year after the investment, rather than getting 7.5% a year for four years. Qualifying expenditure is capital expenditure incurred on new energy-saving plant or machinery for business purposes. The qualifying technologies and products are specified in the Energy Technology List. The current list was published on 14 July 2005 and came into effect on 7 September 2006. The list contains details of the energy-saving criteria that must be met for each of the technology classes. It also contains lists of products that have been certified as meeting those standards. The qualifying technologies are specified in the Energy Technology Criteria List. The list is not fixed, it is periodically reviewed and technologies can be added or removed in the future. CHP qualifies as energy-saving plant and machinery if it is certified as "Good Quality CHP" under the quality assurance scheme for CHP (CHPQA), and has been granted a "certificate of energy efficiency". The ECA is only relevant to investment and therefore represents an incentive to invest in a new CHP scheme without really affecting existing CHP schemes.

Business rates are taxes that businesses have to pay to local authorities. Every non-domestic property has a rateable value, intended to represent the annual rent that would be paid for it in an open market transaction on a fixed valuation date. The amount payable is equal to this rateable value, multiplied by the Uniform Business Rate, equal to 43.3% in 2006/7. While equipment such as a CHP plant would normally increase the rateable value of a property, Good Quality CHP schemes are exempt from business rates and so the value of the scheme is not included in the rateable value of the property. Under the scheme of prescribed assessment (used until 2005), gas-fired power plant (without steam turbines) had a rateable value of £5,000 per MW of capacity, implying that exemption from rates would be worth £2,165 per MW in 2006/7.

3. METHODOLOGY

A typical UK CHP scheme is modelled in an Excel spreadsheet. The monthly variation in heat demand is based on that of the Kings Buildings CHP scheme at the University of Edinburgh. This scheme is sized to meet the minimum monthly heat demand and the electricity produced is all used to just cover the electricity demand of the scheme. It is assumed that the engine is running 60% of the time equally distributed amongst all months apart from February and September, when we assume that the engine is not available 4 days in each of these two months, in order to account for maintenance or grid failure. The system is sized to meet the minimum heat load. In detail, it is sized to meet the total heat demand of the month with the minimum total heat load, August in this case. It is assumed that all the electricity produced is consumed on site.

As indicative values of efficiency[7,8] for the gas engine, 38% electrical efficiency and 40% heat efficiency have been assumed, when the energy input is measured in gross calorific value (GCV).

In UK boiler plants typically run standard boilers[9] and the existing systems are not designed for the low temperatures required for the condensing boilers.[10,11] For this reason, in the general case that is examined in this work, a plant with standard boilers has been considered. However, it should be mentioned that recent regulations are pushing for higher efficiency in boilers[12]. A typical efficiency of 82% in gross calorific value has been assumed here for a standard natural gas UK boiler[13,14].

The total gas consumed and the electricity bought are calculated for each month and for the whole year, separately identifying the gas consumed by the boilers and by the CHP unit (if installed). The spreadsheet also calculates the power efficiency and the quality index of the plant.

These calculations are performed for four case-scenarios of plant configuration and CCL exemption:

Case1 (No CHP): The plant runs only boilers. The plant pays CCL for the gas consumed and the electricity bought.

Case 2 (No CCL exemption): The plant runs boilers and CHP. No CCL exemption is assumed, and so the plant pays the CCL on its gas and electricity purchases. However, in this case the electricity in-house demand is covered by the production of the CHP unit.

Case 3 (Partial CCL exemption): The plant runs boilers and CHP. It is assumed that the plant has to pay the CCL for the gas used in boilers, but the gas used in CHP and the electricity bought for in-house use are exempted from the levy.

Case 4 (Full CCL exemption): The plant runs boilers and CHP. The plant assuming it is a good quality CHP is exempted from the levy on all the gas consumed and the electricity bought.

For each of the three scenarios with CHP, we calculate the annual cost saving in gas and electricity, taking account of the cost of operating and maintaining the CHP unit, compared to using heat-only boilers and buying all the site’s electricity from the grid. First, we calculate this extra cost assuming that there is no CCL exemption for the plant (A). We also calculate it (B) assuming that the CHP scheme has to pay CCL only for the gas used in boilers and (C) assuming that all the gas consumed at the site is exempted from CCL and the electricity brought is also exempted (full CCL exemption) .

Therefore:

A=cost if case 1-cost if case 2; No CCL exemption extra cost (1)

B=cost of case 1-cost of case 3; Partial CCL exemption extra cost (2)

C=cost if case 1-cost if case 4; Full CCL exemption extra cost (3)

The costs A, B and C have been calculated using three different sets of gas and electricity prices[15] - Low, Medium and High. Firstly, gas and electricity prices of 2003 were used (the Low case). Secondly, the higher prices of the second Quarter of 2005 have been used in the calculations (Medium case). Finally, the increase in the prices between the above two years has been calculated and the third set of prices is selected to have the same increase over the Q2 2005 prices (High case). The results are shown in table 1, table 2 and table 3.

These annual cost savings must be compared with the up-front cost of installing the CHP unit. We use a figure of £500,000, which is typical for a 1MWe CHP plant, as our central value for this. The comparison is performed in two ways that might figure in a company's investment appraisal. First, we calculate the simple pay-back period for investing in a CHP plant, rather than simply using boilers and buying power from the grid. The pay-back period is equal to the additional capital cost of the CHP unit, divided by the annual saving in fuel costs (taking account of CHP operating costs). This is a very simple measure, but one widely used within industry when making investment decisions. The results are presented in Table 4.

Second, we calculate the Internal Rate of Return for the investment. This is the cost of capital at which the project would just break even if it had to borrow the money when the CHP unit was installed, and pay it back, with interest, from the savings in fuel costs. Using the IRR allows us to consider the timing of expenditure and cost savings. In particular, it allows us to include the value of the Enhanced Capital Allowances received for investment in CHP plant, which allow the company to reduce its Corporation Tax bill in the year that an investment is made, rather than having to wait four years until the full benefit is received. We calculate the IRR for two project lengths – three years and five years – in line with the short timescales often used to assess investments in energy efficiency. We calculate it with and without the benefit of the ECAs, to show the impact of this second incentive for investment in CHP plant. For sensitivity analysis, we have considered the three sets of fuel prices described above, and capital costs that are 20% above and 20% below our central figure. These results are presented in Table 5 and Table 6

4. RESULTS-DISCUSSION

The electrical efficiency of the scheme was found to be 21% and therefore just meets the requirement for CCL exemption. Furthermore, the quality index of the scheme is 122, which is again exactly within the limit required for the plant to be categorized as a 'good quality CHP plant'. Therefore, it is found that a typical UK CHP plant, being sized to meet the minimum heat load, just meets the two minimum requirements of the British legislation for being exempted from the CCL. The production of the gas engine seems to only serve this purpose. The absence of a thermal store does not allow for a bigger engine or more intensive CHP production than just meeting the minimum heat demand. A thermal store would allow the CHP plant to store heat when it is not needed, and it would allow the CHP plant to go offline when electricity import prices are low because heat load can still be met from the store. Clearly, the absence of heat storage influences the size and the operating hours of the engine; if the engine was larger then by running the CHP all the time the plant would have either to dump heat, which is undesirable, or to stop the engine. What happens in practice in cases of excess heat production is that the plant stops the engine in case more heat is produced than the heat demand.

The changes in annual costs are shown in Table 1, Table 2 and Table 3 for the cases of Low, Medium and High fuel prices. The left-hand column shows the amount spent on buying gas and electricity for the site. Moving from heat-only boilers to a CHP scheme reduces the amount of energy required by 27%, weighting gas and electricity at their respective market prices. The additional benefits of CCL exemption reduce the cost by another £37,000 (bottom line), or £21,000 with only the partial exemption (third line). This exemption is proportionately less valuable when fuel prices are high, in Table 3, than when they are low (Table 1).

We also need to consider the costs of operating and maintaining the CHP plant. These are assumed invariant to fuel prices, and therefore have a bigger proportional impact on the plant's overall saving when fuel prices are low. With low (2003) fuel prices, the overall saving on the annual costs of the boiler-only plant is 18% with no CCL exemption, or 27% with the full exemption (Table 1). With high fuel prices (Table 3), the saving ranges from 22% (no exemption) to 27% (full exemption).

	Energy input cost (£)	Benefit of CHP before other costs (£)	Benefit of CHP before other costs (%)	Engine O&M costs (£)	Energy input plus O&M costs (£)	Net benefit of CHP (before capital cost) (£)	Net benefit of CHP (before capital cost) (%)
1.Cost when just boiler	403,003				403,003		
2.Cost of CHP with no CCL exemption	294,484	108,519	26.93%	35,279	329,763	73,240	18.17%
3.Cost of CHP with partial CCL exemption	273,349	129,653	32.17%	35,279	308,628	94,374	23.42%
4.Cost of CHP with full CCL exemption	257,465	145,537	36.11%	35,279	292,744	110,258	27.36%

Table 1 CCL benefit on CHP, 2003 gas and electricity prices (Low Case)

	Energy input cost (£)	Benefit of CHP before other costs (£)	Benefit of CHP before other costs (%)	Engine O&M costs (£)	Energy input plus O&M costs (£)	Net benefit of CHP (before capital cost) (£)	Net benefit of CHP (before capital cost) (%)
1.Cost when just boiler	517,645				517,645		
2.Cost of CHP with no CCL exemption	378,234	139,411	26.93%	35,279	413,513	104,132	20.12%
3.Cost of CHP with partial CCL exemption	357,100	160,545	31.01%	35,279	392,379	125,266	24.20%
4.Cost of CHP with full CCL exemption	341,216	176,429	34.08%	35,279	376,495	141,150	27.27%

Table 2 CCL benefit on CHP, 2005 gas and electricity prices; 0.33 increase in the gas cost and 0.32 increase in the electricity cost over 2003 prices (Medium Case)

	Energy input cost (£)	Benefit of CHP before other costs (£)	Benefit of CHP before other costs (%)	Engine O&M costs (£)	Energy input plus O&M costs (£)	Net benefit of CHP (before capital cost) (£)	Net benefit of CHP (before capital cost) (%)
1.Cost when just boiler	669,408				669,408		
2.Cost of CHP with no CCL exemption	489,228	180,179	26.92%	35,279	524,507	144,901	21.65%
3.Cost of CHP with partial CCL exemption	468,094	201,314	30.07%	35,279	503,373	166,035	24.80%
4.Cost of CHP with full CCL exemption	452,210	217,198	32.45%	35,279	487,489	181,919	27.18%

Table 3 CCL benefit on CHP, High gas and electricity prices; 0.33 increase in the gas cost and 0.32 increase in the electricity cost over 2005 prices (High case)

These annual savings must be compared with the initial cost of the CHP equipment. We do this in Table 4, which shows the simple pay-back periods for different CCL exemption policies, fuel prices, and engine costs. For many companies, energy efficiency projects will only be adopted if they have a pay-back period of two years or less.[16] Even with high fuel prices, the full CCL exemption and a low equipment cost, the CHP project fails to meet this demanding target. However, the table clearly shows that the CCL exemption can reduce the payback period quite significantly, and the reduction is greatest in the cases with long payback periods.

Taking a higher threshold of five years, we see that the exemption makes a difference if CHP is expensive for medium energy prices (2005) but does not help if CHP is expensive for the low (2003) prices while for high prices it worth any way to do the project. Secondly, we assume that this threshold is 4 years. In this case, it makes a difference if CHP is expensive for high energy prices and if CHP has its actual cost for medium energy prices, while for low prices (2003) it makes a difference only if CHP is cheap and full CCL exemption applies.

		actual engine cost	20% decrease	20% increase
Engine cost(£):		500000	400000	600000
Pay back period in years=cost of the engine (£)/net benefit(£)				
for 2003 prices:	CHP with no CCL exemption	6.8	5.5	8.2
	CHP with partial CCL exemption	5.3	4.2	6.4
	CHP with full CCL exemption	4.5	3.6	5.4
for 2005 prices:	CHP with no CCL exemption	4.8	3.8	5.8
	CHP with partial CCL exemption	4.0	3.2	4.8
	CHP with full CCL exemption	3.5	2.8	4.3
for high prices:	CHP with no CCL exemption	3.5	2.8	4.1
	CHP with partial CCL exemption	3.0	2.4	3.6
	CHP with full CCL exemption	2.7	2.2	3.3

Table 4 Pay back period for different engine prices and gas and electricity prices- effect of the CCL exemption

Our final set of results are presented in Table 5 and Table 6. These tables show the sensitivity of the internal rate of return for a CHP project to energy prices, the capital costs of CHP, whether there is a CCL exemption, and whether Enhanced Capital Allowances are given.

Table 5 presents the upper limit of the internal rate of return (or cost of capital) of a five year project to break even. That is, if the firm's cost of capital is less than the percentages presented in Table 5, then the project will save more than enough money to pay back the money invested in it, with interest, within five years. Over the last ten years, UK companies have had an average return on capital of between 11% and 14%.[17] The 2005 Energy Review[18] used a figure of 10% when calculating the cost of various technologies for electricity generation. In practice, however, firms typically seek rather higher internal rates of return before a project is considered to be viable.

If we use a figure of 15% and a five-year project life, then high energy prices would make the project viable, regardless of government policy or the initial cost of the plant. In the case of medium energy prices, either of the two policies (accelerated depreciation or CCL exemption) is sufficient to make the project viable for the actual CHP investment cost, while the CCL exemption, but not accelerated depreciation, would make the project viable if CHP is expensive to install. In the case of low energy prices, the project is never viable if CHP is expensive, while for cheap CHP and for the actual CHP cost, the project is viable if the CCL exemption, only, applies; the accelerated depreciation is inadequate on its own to make the project viable in this case. Clearly the impact of CCL exemption on the internal rate of return is higher than that of the accelerated depreciation. For 2005 energy prices and actual engine cost, the accelerated depreciation increases the internal rate of return from 14% to 18%, while the CCL exemption rises from 14% to 25%. This difference in the increase resulting from the two policies is more pronounced for low electricity prices and low engine costs.

Decrease/increase in engine cost		actual cost	20% decrease	20% increase
Engine cost(£)		500000	400000	600000
Internal rate of return of a 5-year project				
for 2003 prices:	CHP with no CCL exemption and no accelerated depreciation	5%	14%	-2%
	CHP with no CCL exemption but accel depreciation	6%	13%	1%
	CHP with full exemption and no accel depreciation	16%	27%	8%
	CHP with full exemption and accelerated depreciation	20%	29%	13%
Decrease/increase in engine cost		actual cost	20% decrease	20% increase
Engine cost(£)		500000	400000	600000
Internal rate of return of a 5-year project				
for 2005prices:	CHP with no CCL exemption and no accelerated depreciation	14%	25%	7%
	CHP with no CCL exemption but accel depreciation	18%	26%	11%
	CHP with full exemption and no accel depreciation	25%	37%	16%
	CHP with full exemption and accelerated depreciation	30%	40%	22%
Decrease/increase in engine cost		actual cost	20% decrease	20% increase
Engine cost(£)		500000	400000	600000
Internal rate of return of a 5-year project				
for high prices:	CHP with no CCL exemption and no accelerated depreciation	26%	38%	17%
	CHP with no CCL exemption but accel depreciation	31%	42%	23%
	CHP with full exemption and no accel depreciation	35%	49%	26%
	CHP with full exemption and accelerated depreciation	42%	54%	33%

Table 5 Internal rate of return for a 5 year project

Decrease/increase in engine cost		actual cost	20% decrease	20% increase
Engine cost(£)		500000	400000	600000
Internal rate of return of a 3-year project				
for 2003 prices:	CHP with no CCL exemption and no accelerated dep	-14%	-4%	-21%
	CHP with no CCL exemption but accel dep	-11%	-3%	-16%
	CHP with full exemption and no accel dep	-2%	10%	0%
	CHP with full exemption and accelerated depreciation	4%	13%	-3%
for 2005prices:	CHP with no CCL exemption and no accelerated dep	-4%	8%	-12%
	CHP with no CCL exemption but accel dep	2%	11%	-5%
	CHP with full exemption and no accel dep	7%	21%	-2%
	CHP with full exemption and accelerated depreciation	15%	26%	6%
for high prices:	CHP with no CCL exemption and no accelerated dep	8%	22%	-1%
	CHP with no CCL exemption but accel dep	16%	27%	8%
	CHP with full exemption and no accel dep	19%	34%	8%
	CHP with full exemption and accelerated depreciation	27%	41%	18%

Table 6 Internal rate of return for a 3 year project

For shorter project lives the internal rate of return to break even decreases significantly. Table 6 presents the upper limit of the cost of capital for a three year project to break even. With the low 2003 electricity prices, the project is unable to reach the 15% threshold IRR for any policy combination or initial cost we study. For medium energy prices (2005) CHP is viable with a low initial cost only if it gains an exemption from the CCL, whereas the actual engine cost implies that both CCL exemption and accelerated depreciation are required to make the project (just) viable. For high energy prices and initial cost, CHP is viable only if both policies apply, while for the actual initial cost CHP will be viable if either policy is applied. With the cheap initial cost and high energy prices, CHP would be viable without either policy. Just as with a five year project period, it is clear that the CCL exemption has more impact on the IRR than accelerated depreciation.

5. BREAK-EVEN ENERGY PRICES

The attractiveness of a CHP plant is heavily dependent on the relative prices of gas and electricity. The higher the price of electricity, relative to that of gas, the more likely it is that a given CHP scheme will be profitable. We have therefore calculated the break-even combinations of gas and electricity prices for our CHP plant, with six policy cases. The plant will be profitable, given a policy choice, if the combination of gas and electricity prices considered is above the line for that policy, and unprofitable if the prices are below the break-even line.

Our base case is shown in figure 1 – we assume an engine cost of £500,000, a five-year project life, and a required internal rate of return of 15%. The first policy, and the one producing the highest break-even electricity price, is that CHP schemes receive no support. The second policy, supporting CHP only via the exemption from business rates, produces only a marginal reduction in the break-even price. For plausible gas prices, the annual expenditure on the CHP scheme is of the order of several hundred thousand pounds, and so a rate rebate worth £2,000 has almost no impact. Enhanced capital allowances produce a slightly greater impact on the break-even electricity price, but it is still small. Our fourth policy case gives the CHP partial exemption from the CCL – this is the case 3 of section 3. This has roughly twice as much impact as the enhanced capital allowances. The impact of full CCL exemption, our fifth policy, is roughly twice as great, in this example. Each of the lines so far considers a single support policy in isolation, but the final, lowest, line shows the impact of all three current policies together.

The figure also shows the electricity and gas prices paid by the "other" sector (dominated by commercial users) from the Digest of UK Energy Statistics, table 1.6, for three recent years. In our base case, requiring a 15% IRR over five years, our CHP plant would have been marginally profitable, even without support, given the prices ruling in 2001 and 2005, but would have been unprofitable in 2003, had it not received the CCL exemption.

We present some sensitivity analyses in figures 2-5. These show, respectively, the impact of requiring only a 10% IRR, a ten-year project life, and lower (£400,000) and higher (£600,000) engine costs. The break-even lines are shifted downwards, as expected, in all but the last of these cases. The pattern of the lines does not change, however – the CCL exemption is still by far the most effective policy of the three in promoting CHP.

We note that the lines are approximately parallel in all five figures. This is because the value of the incentives is not linked to the price of gas or electricity, since the CCL is a fixed tax. This would imply that the proportionate value of the incentives are much greater when the prices of gas and electricity are low. If the gas price rises by £1/MWh, the break-even electricity price rises by £1.34. In the electricity market, however, gas is converted in power at a thermal efficiency of around 55%, or less in the older plants. This implies that a £1/MWh rise in the price of gas would lead to an increase in the price of electricity of nearly £2/MWh. In other words, as the price of gas rises, the market price of electricity is likely to rise much faster than the break-even price of power calculated for our CHP scheme. The CHP scheme is more likely to be profitable when gas prices are high. It is therefore appropriate that the government incentives have their greatest proportional impact when gas prices are low – there is little point in providing more generous subsidies at times when CHP schemes are likely to be in profit at the market prices.

6. CONCLUSIONS

The UK government promotes CHP via three main incentives – exemption from business rates, enhanced capital allowances, and exemption from the Climate Change Levy. A typical UK CHP scheme is modelled in an Excel spreadsheet for the analysis and evaluation of these incentives. It was found that CHP plants sized to meet the minimum heat load, since there is no heat storage facility in most of them, just meet the requirements for 'good quality' CHP and therefore exemption from the CCL. The extra cost to run a plant with only boilers in case of partial and full CCL exemption was calculated for different energy prices. We showed how the CCL exemption raised the annual cost savings from running the CHP plant, and how this becomes less pronounced as energy prices increase, since the CCL remains constant. The annual cost savings were compared with the up-front cost of installing the CHP unit. Firstly, the sensitivity of the beneficial effect of the CCL exemption on the capital cost of CHP has been studied using as a criterion the pay back time and it has been shown that the CCL exemption can reduce the payback period quite significantly. However, the beneficial effect is less pronounced for high energy prices and low engine costs. Secondly, a study was conducted to compare the impact of CCL with the impact of the accelerated depreciation on a CHP project. This was done by calculation of the IRR for different energy prices, capital costs, and for five and three year project lifetimes. We showed that the CCL exemption has a much greater impact on the IRR than the accelerated depreciation. Again, high energy prices and low engine costs reduce the benefit of the CCL exemption, in exactly those circumstances when it is less likely to be required. Finally, we calculated the break-even gas and electricity prices for our scheme, and showed how these varied with the policy instruments chosen. The impact of exemption from business rates was minimal, but the exemption from the CCL will have been sufficient to make some otherwise unprofitable schemes profitable at times of low energy prices.

While we are not arguing for the other policies promoting the adoption of CHP to be dropped, this work shows that their impact is likely to be much lower than that of the CCL exemption. If each policy to promote CHP implies an administrative burden on government and, if it has to be claimed explicitly, on CHP operators, we recommend that these burdens could be minimised by channelling a chosen level of support through the minimum number of significant measures.

ACKNOWLEDGEMENTS

The article is part of the EU-funded DESIRE project (Dissemination strategy on Electricity balancing for large Scale Integration of Renewable Energy). This is funded under the Framework 6 Programme.

We also acknowledge the assistance of PB Power in providing background technical and market advice on CHP operation in the UK.

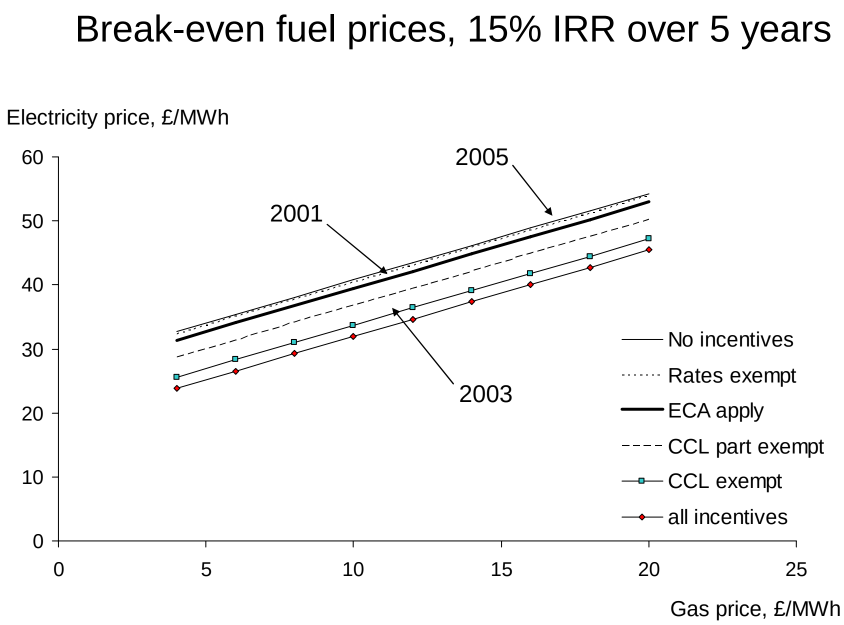


Figure 1

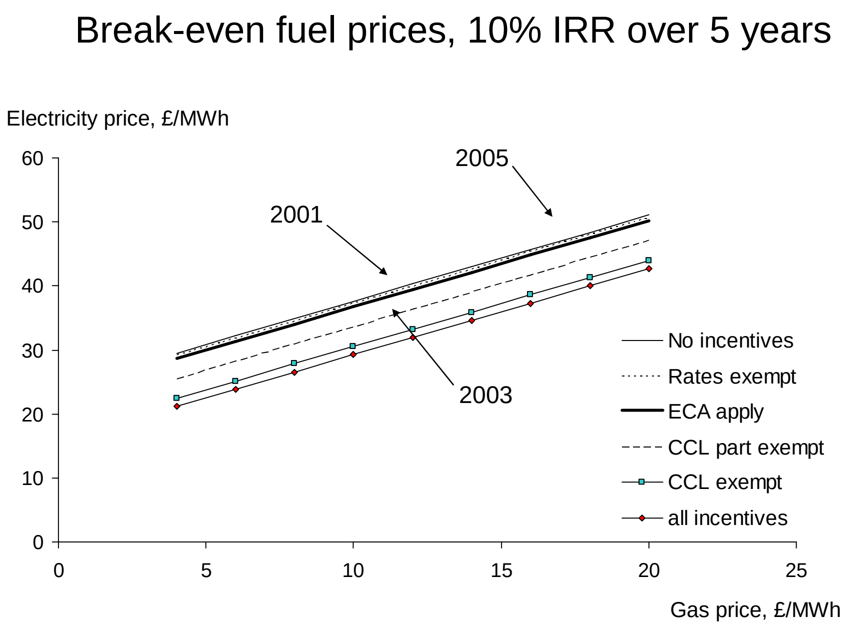


Figure 2

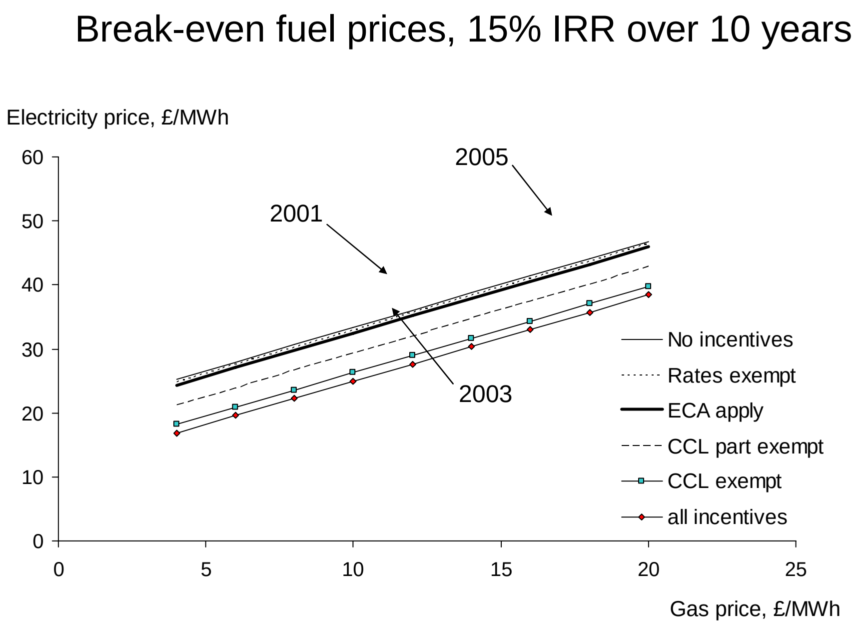


Figure 3

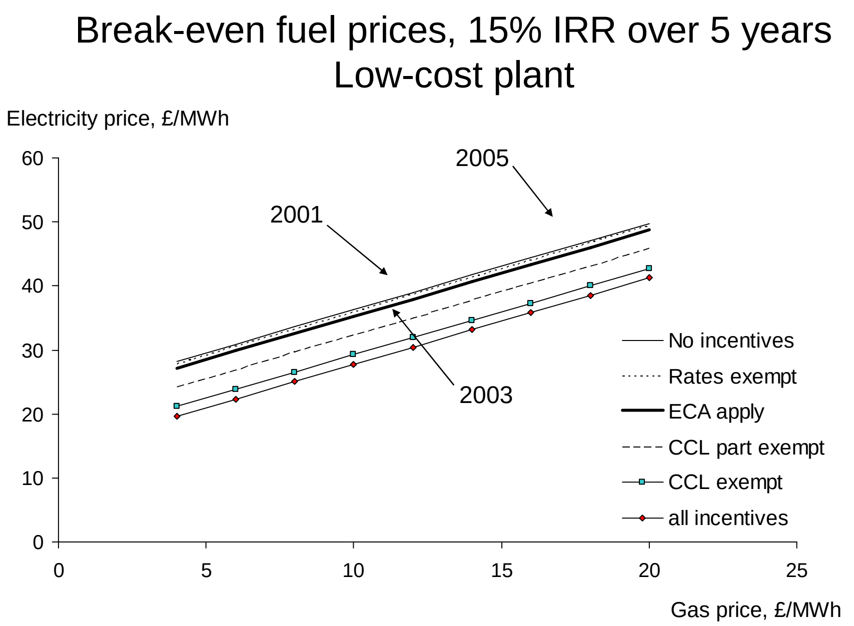


Figure 4

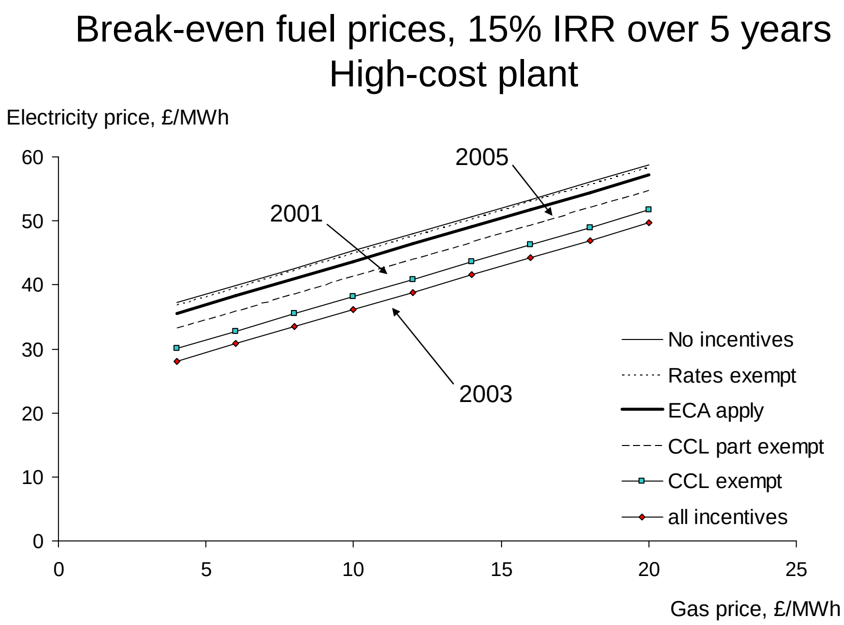


Figure 5

---

[1] Gustafsson S.I. and Karlsson B.J. Heat accumulators in CHP networks. Institute of Technology; Energy Systems; Linköping, Sweden; 1992; S 581 83,

[2]the Government's Strategy for Combined Heat and Power to 2010 http://www.defra.gov.uk/environment/energy/chp/pdf/chp-strategy.pdf

[3] Defra, UK, Climate change agreements, The climate change levy , 6 June 2005 www.defra.gov.uk/environment/ccl/intro.htm

[4] CHPQA. Quality Assurance for Combined Heat and Power. The CHPQA Standard. Issue 1. November 2000 www.chpqa.com/guidance_notes/documents/Standard_-_FINAL_VERSION.pdf

[5] The gross calorific value is the higher calorific value; it supposes that the water of the combustion is condensed entirely. The heat contained in this water is recovered.

[6] HM Revenue& customs, ECA-Part 1: Overview of Enhanced Capital Allowances for Energy Saving Investments. http://www.hmrc.gov.uk/capital_allowances/eca-guidance.htm

[7] Interview with Mr Ian Hills, Clark Energy Ltd, UK, Runcorn, 3-2-06

[8]www.clarke-energy.co.uk, www.energ.co.uk, www.cogengo.co.uk,

[9]]Interview with Paul Woods, James Eland and Dominic Cook from PB power, Birmingham 21-9-05.

[10] Section 4.3.1. Operating temperatures for hydronic systems in: CIBSE. Guide B1-Heating. CIBSE 2002.

[11] Section B1-13 and section B1-14 in: CIBSE. Guide B-Volume B. CIBSE 1986.

[12] ODPM Building Regulations. Part L-Conservation of Fuel and Power. 2006.

[13] Interview with Mr Clive Bannocks from YGNIS boiler suppliers, Birmingham, 6-12-05

[14] Interview with Dr David Somervell and Dr David Barratt from Edinburgh University, Edinburgh, 9-12-05

[15] Department of Trade and Industry (dti), www.dti.gov.uk/energy

[16] Woodruff, M.G., T.W. Jones, J. Dowd, J.M. Roop, H.E. Seely and M.R. Muller, Evidence from the Industrial Assessment Program on Energy Investment Decisions by Small and Medium-Sized Manufacturers, Proceedings of the IECE 32nd Intersociety Energy Conversion Engineering Conference, 1997

[17] Source: Office for National Statistics, Economic Trends

[18] Department of Trade and Industry (2006) *The Energy Challenge: Energy Review Report 2006*, Cm 6887, London, The Stationery Office

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Aikaterini Fragaki and David Toke, The University of Birmingham
E-mail	d.toke@bham.ac.uk
Title of dissemination	Balancing Act
Type of activity	Article in trade magazine
Title of forum	Energy Engineering
Language	English
Date of dissemination	February 2007
Place of dissemination	UK
Brief abstract / description of dissemination activity	The cost of integrating fluctuating renewables is much less than is thought in the short term, and will be considerably reduced in the long term using the Danish system of CHP with thermal stores.
Audience impact assessment	Through the trade journal, a targeted dissemination of results takes place and knowledge is spread to the energy industry in the UK.
Dissemination	Available through www.energyengineering.co.uk

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Bernhard Lange, ISET
E-mail	blange@iset.uni-kassel.de
Title of dissemination	Wind power forecasting
Type of activity	Manuscript for a book chapter
Title of forum	Book ‘Renewable Electricity and the Grid’ by Godfrey Boyle
Language	English
Date of dissemination	March 15th 2007
Place of dissemination	
Brief abstract / description of dissemination activity	The chapter explains the role wind power forecasting plays in tackling the challenge of the fluctuating power output of wind power. In the electricity system, supply and demand must be equal at each time. Thus, in an electricity system with an important share of wind power, new methods of balancing supply and demand are needed. Therefore wind power forecasting is the prerequisite for the integration of a large share of wind power in an electricity system, as it links the weather dependent production with the scheduled production of conventional power plants and the forecast of the electricity demand, the latter being predictable with reasonable accuracy.
Audience impact assessment	Book is still in publishing phase, so the audience impact assessment is not available yet
Dissemination	Included after this firm

Manuscript for a chapter of the book

Renewable Electricity and the Grid
by Godfrey Boyle

Wind power forecasting

Bernhard Lange, Kurt Rohrig, Florian Schlögl, Ümit Cali, Rene Jursa

Institut für Solare Energieversorgungstechnik e.V. (ISET), Königstor 59, D-34119 Kassel, Germany, e-mail: blange@iset.uni-kassel.de

12.3.2007

Content

1 INTRODUCTION 3

2 APPLICATIONS OF WIND POWER FORECASTING 4

3 STEPS OF A FORECASTING SYSTEM 5

4 NUMERICAL WEATHER PREDICTION 6

5 DIFFERENT APPROACHES FOR THE POWER OUTPUT FORECAST 7

6 FORECAST HORIZON 8

7 REGIONAL UPSCALING 10

8 SMOOTHING EFFECT 13

9 FORECAST ACCURACY 14

10 EXAMPLE: THE WIND POWER MANAGEMENT SYSTEM (WPMS) 17

11 'LEARNING CURVE' OF THE FORECASTING ACCURACY 19

12 EXAMPLES FOR CURRENT RESEARCH 20

12.1 Improved representation of the atmospheric boundary layer 20

12.2 Multi-model approach for forecasting methods 21

12.3 Multi-model approach for numerical weather forecast models 23

12.4 Prediction of the forecast uncertainty 24

13 FUTURE CHALLENGES 25

14 SUMMARY FEJL! BOGMÆRKE ER IKKE DEFINERET.

1 Introduction

Electricity generated from wind power will play an important role in the future energy supply in many countries. This implicates the need to integrate this power into the existing electricity supply system, which was mainly designed for large units of fossil fuel and nuclear power stations. Wind power has different characteristics and therefore this integration leads to some important challenges from the point of view of the electricity system.

The availability of the power supply generated from wind energy varies fundamentally from that generated conventionally from fossil fuels. The most important difference is that wind power generation depends on the availability of the wind, i.e. it is weather dependent. In contrast to conventional power plants, which are controlled to produce power according to the demand, wind power usually is produced according to the available wind. This also means that the power output is fluctuating with the wind variations. In the electricity system, supply and demand must be equal at each time. Thus, in an electricity system with an important share of wind power, new methods of balancing supply and demand are needed.

Wind power forecasting plays a key role in tackling this challenge. It is the prerequisite for the integration of a large share of wind power in an electricity system, as it links the weather dependent production with the scheduled production of conventional power plants and the forecast of the electricity demand, the latter being predictable with reasonable accuracy. This is illustrated in the following example.

Figure 1 shows the electricity demand of Germany for one week as an example (upper curve). The first day was a public holiday with a relatively low electricity demand, comparable to that of day four, which was a Sunday. Saturday shows a slightly higher demand and also a different temporal course. The load was again slightly higher on the Friday between the holiday and the weekend. The last three days show the typical weekday load curves. This load curve is readily predictable, even for a rather atypical week as shown in the example, and the conventional power plants are scheduled such that their prediction follows the predicted load curve. Deviations of the actual from the predicted load are balanced by the use of balancing power.

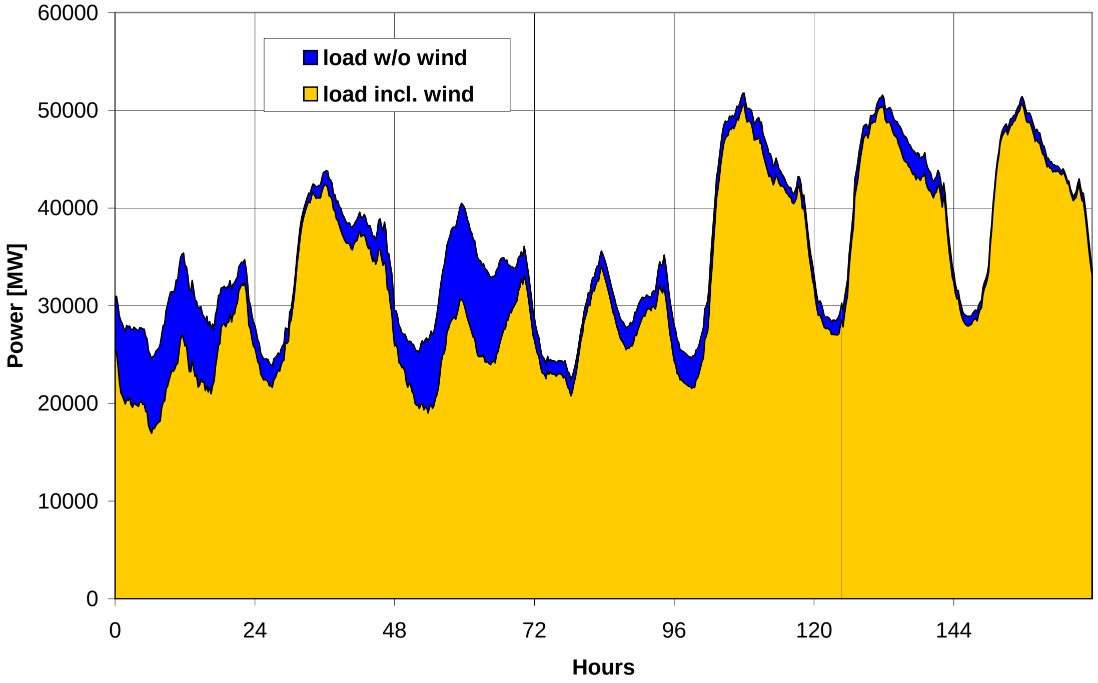


Figure 1: Load and wind power generation for one week in Germany (1.-7.5.2003)

The dark band shown in the graph was the share of electricity generated by wind power in Germany during this week. The wind power production was varying between almost zero on the last day and up to about 10 GW on day three. Conventional power plants had to supply only the share of the load shown by the lower curve. If the wind power generation was not predicted, it would appear as an additional and unknown ‘negative load’ and would require an extremely large use of balancing energy. This is technically and economically undesirable. Instead, the forecast power output from wind power is used together with the load forecast to schedule the conventional power plants. In this way only the errors in the forecasts have to be balanced by balancing energy. This also shows clearly that the forecast error determines the need of balancing energy for the integration of wind power.
A wind power forecast is indispensable for system operation and security. Its accuracy is directly connected to the need for balancing energy and hence to the cost of wind power integration. Consequently, a large amount of research has been directed towards the development of good and reliable wind power forecasts in the last years and many different forecasting systems with different approaches have been developed. In countries with a substantial share of wind power in the electricity system like Denmark, Germany or Spain, wind power forecasting systems are already an essential part of grid and system control.

2 Applications of wind power forecasting

The most important application for wind power forecasting is to reduce the need for balancing energy and reserve power, which are needed to integrate wind power into the balancing of supply and demand in the electricity supply system, i.e. to optimise the power plant scheduling. This leads to lower integration costs for wind power, lower emissions from the power plants used for balancing and subsequently to a higher value of wind power.

A second application is to provide forecasts of wind power feed-in for grid operation and grid security evaluation. To assess the security of the grid and to operate it, e.g. for maintenance and repair, the grid operator needs to know the current and future wind power feed-in at each grid connection point.

The objectives of a wind power forecast therefore depend on the application:

- For optimised power plant scheduling and power balancing, an accurate forecast of the wind power generation for the whole control zone is needed. The relevant time horizon depends on the technical and regulatory framework, e.g. the types of conventional power plants in the system and the trading closure times.
- For determining the reserve power which has to be held ready to provide balancing energy, a prediction of the accuracy of the forecast is needed. As the largest forecast errors determine the need for reserve power, these have to be minimised. In Germany, the relevant forecast horizon is usually rather long, i.e. predicted one day ahead.
- For grid operation the current and forecast wind power generation in each grid area or grid connection point is needed. This requires a forecast for small regions or even single wind farms. For grid management, shorter time horizons are often relevant. Switching and other grid operations do not have a long lead time and therefore a higher accuracy of short-term forecasts is more important.

3 Steps of a forecasting system

In producing a wind power forecast, different steps can be distinguished:

- Numerical weather prediction
- Wind power output forecast
- Regional upscaling

As the first step, a weather prediction including the forecast of the wind speed and possibly some other meteorological parameters is needed for a wind power forecast. This is provided by numerical weather prediction (NWP) models. Most often, two or more hierarchical levels with different NWP models and increasing resolution are used (see section 4). Very simple systems use as a substitute for NWP models measured wind speeds from a location in the direction of the mean pressure systems movement. It is possible to compute forecasts without weather prediction from actual measurements of power output, but only for very short forecast horizons.

The NWP data are used as input to the next step, the wind farm power output forecasting. This takes into account the local meteorological influences on the wind speed and direction, the power conversion characteristics of the turbine, wind farm shading and other effects which influence the power output. Different approaches and combinations of approaches have been developed and are in use (see section 5). For forecasts with a shorter forecast horizon, online measured wind speeds and/or wind farm power output are used as additional input to the forecasting (see section 6).

If the forecast is needed for a larger region with very many wind farms or wind turbines, forecasts are compiled only for some representative wind farms and the results from these are scaled-up to regional forecasts as a third step (see section 7).

4 Numerical weather prediction

Weather forecasts from numerical weather prediction models (NWP-models) are the most essential input needed for almost all wind power forecast models. Usually a model chain of hierarchical levels with different NWP models and increasing resolution is used.

The model chain starts with meteorological measurements and observations all over the globe, done by meteorologists, weather stations, satellites, etc. All available data are used as input to a global NWP model, which models the atmosphere of the entire earth. The NWP model calculates the future state of the atmosphere from the physical laws governing the weather. Since these calculations are very computationally expensive, the resolution of a global model has to be rather coarse (see Figure 2 left). Global models are in operation at only about 15 national weather services.

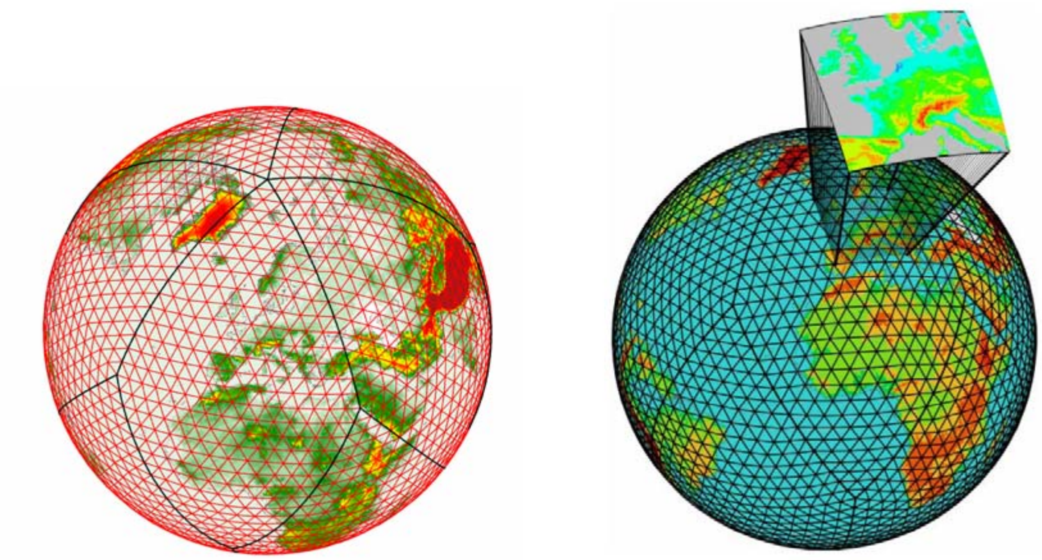


Figure 2: Horizontal grid of a global numerical weather prediction model and enlarged area covered by a local area model (figures taken from DWD)

To provide more accurate weather forecasts, local area models (LAM) are used, which cover only a small part of the earth, but can be run with a much higher resolution (see Figure 2 right). These models use as input the forecasts of the global model and calculate a weather forecast taking into account the local characteristics of the terrain.

NWP models are usually run operationally by national weather services. Most of these only run LAM for their region of interest and use data from other global models as input. Some commercial companies also run NWP models and there also exist dedicated service companies running NWP models for wind power forecasting.

One example of a LAM is the LME model [1] of the German Weather Service (DWD). It covers central Europe with 325 times 325 grid cells. This leads to a horizontal resolution of about 7 times 7 km. The forecast horizon of the operational model is 48 hours and the resolution 1 hour. Model runs are started twice daily at 00 UTC and 12 UTC.

In some model systems a third step is performed using a high resolution mesoscale model with an even higher resolution. This is especially important if the LAM available has low resolution and the terrain is complex. The mesoscale models can either be run by the provider of the weather prediction data, i.e. a weather service provider, or as part of the wind power forecast model.

In practical application, often different NWP model data are available for a wind power forecast. Important criteria for the selection of the most appropriate NWP model are:

- Area covered
- Spatial and temporal resolution
- Forecast horizon
- Accuracy
- Number of runs and their calculation time

5 Different approaches for the power output forecast

The aim of a wind power forecast is to link the wind prediction of the NWP model to the power output of the turbine. Three fundamentally different approaches can be distinguished:

- The *physical approach* aims to describe the physical process of converting wind to power and models each of the steps involved.
- The *statistical approach* aims at describing the connection between predicted wind and power output directly by statistical analysis of time series from data in the past.
- Finally the *learning approach* uses artificial intelligence (AI) methods to learn the relation between predicted wind and power output from time series of the past.

In practical applications the methods are sometimes combined or mixed. Models with a physical approach almost always use data from the past to tune their models or use model output statistics (MOS) for a correction of the result. On the other hand, models using statistical or AI methods often use knowledge of the physical processes like the shape of the power curve in designing their models.

The physical approach contains a chain of models of the different physical processes involved:

- Wind conditions at the site and hub height of the turbines
- Wind farm shading effects
- Turbine power curve
- Model output statistics (MOS)

The wind prediction of a NWP model represents a mean wind speed over the area of one grid cell of the model at a certain height. As a first step, the site specific wind speed and direction at hub height of the turbines has to be calculated. The models used for this are either micrometeorological models like the WAsP [2] model and/or flow models, usually mesoscale models like MM5 [3]. These models take into account the influence of the vertical wind speed profile, the orography of the terrain, the surface roughness and thermal effects. In a second step, wind farm shading effects are calculated by a wind farm model, e.g. PARK [4] or FLaP [5]. The turbine power curve is then used to convert the wind speed at each turbine into the expected power output. Finally, model output statistics (MOS) are used to correct the results for systematic deviations caused either by uncertainties in the information needed by the models or by inaccuracies in the models. MOS is a statistical correction method based on time series of the past. It is essential for good forecasting quality of a physical model, since the physical processes are highly complex and the information needed for the models often has limited accuracy. The models need detailed knowledge about the wind farms to be forecast, e.g. the terrain around the wind farm, the layout of the farm and the power curve of the turbines.

Statistical approaches analyse the connection between weather forecasts and power production from time series of the past, and describe this connection in a way that enables it to be used for the future.
Like statistical models, artificial intelligence methods also describe the connection between input data (the predictions of the NWP model) and output data (wind farm power output). But instead of an explicit statistical analysis they use algorithms which are able to implicitly describe non-linear and highly complex relations between these data. Different methods are used for this, e.g.:

- Artificial neural networks
- Support vector machines
- Nearest neighbour search

For both the statistical and AI approach, long and high quality time series of weather predictions and power output of the past are of essential importance.
Each of these approaches is used in practical applications. The physical approach is e.g. used in the models Prediktor ([6], [7]) and Previento ([8], [9]). The WPPT ([10], [11]) model uses a statistical approach, while the WPMS ([12], [13]) model uses an AI approach. For an overview over different models, see [14], [15], [16]. The main advantages and drawbacks of different approaches for the power output forecasts are summarised in Table 1.

Table 1: Summary of main advantages and drawbacks of different approaches for the power output forecast

Statistical and artificial intelligence approaches	**Physical approach**
+ No physical insight necessary + Fast calculation – Depending on high quality and long-term measurement data – Situations with limited numbers of observations difficult	+ Chance to understand physical behaviour + Measurement data less important – Needs extensive information about wind farms – High effort in set-up

6 Forecast horizon

The forecast horizon is the time period between the time at which the forecast is available and the forecast point in time. Different forecasts are used for different purposes and their forecast horizons depend on the requirements of the user, stemming from technical and regulatory conditions and on the feasibility of forecasting.

From the meteorological and climatological point of view, one can distinguish long-term or seasonal forecasts with a forecast horizon of several months, medium-term forecasts with a range of up to 2 weeks, short-term forecasts for the next few days and very-short term forecasts for a forecast horizon of up to one day. Generally the forecast accuracy decreases with increasing forecast horizon.
For wind power forecasting currently deterministic forecasts are used up to a forecast horizon of 3 to 5 days. Mainly two forecast horizons have to be distinguished: The day-ahead forecast and the short-term forecast. The day-ahead forecast is mainly used for day-ahead power trading. The forecast horizon therefore depends on the organisation of the trading, e.g. the gate closure time and the trading days. An example for a gate closure time of 12 o’clock for the next day is shown in Figure 3. The NWP model starts running at midnight with the observations from the day before. It finishes calculation around 7 o’clock in the morning and sends the information to the wind power forecasting system. This usually has a very short calculation time and the results are available a few minutes later. They are analysed and used for trading the power for the next day until at 12 o’clock the trading ends. This means that the calcualtion of the forecast starts 48 hours ahead, counted from the start of the NWP model. If there is no trading at weekends and pubic holidays lead time for the calculation for the ‘day-ahead’ trading actually can be 96 hours or longer.

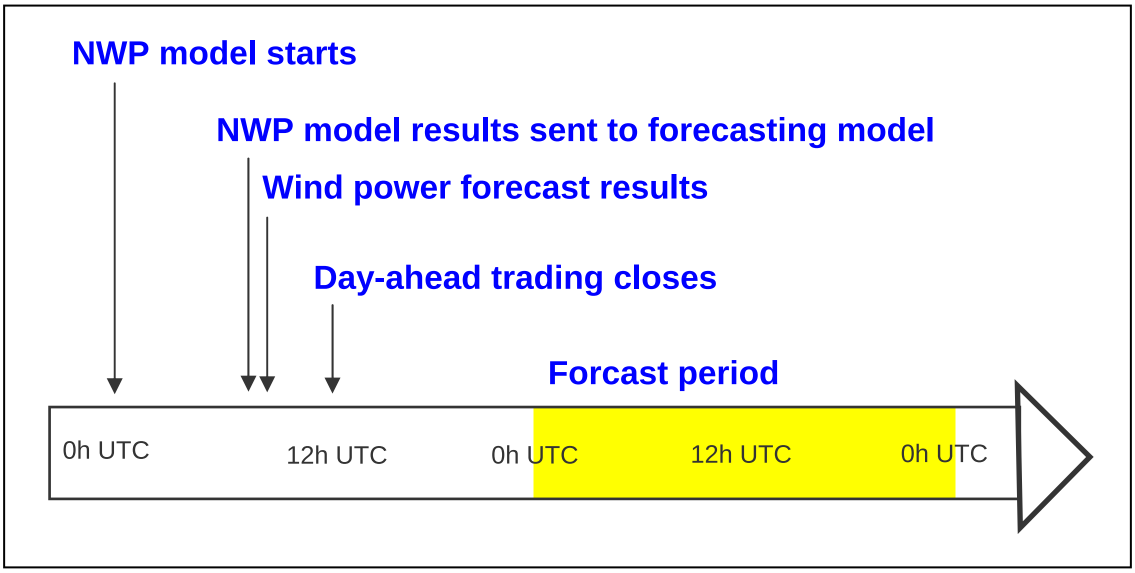


Figure 3: Typical time schedule for wind power forecasting used for day-ahead trading

Short-term wind power forecasting is mainly used for intra-day trading and grid operation and security. Its main characteristic is that it utilises online data from measurements of actual power output and/or wind speed. For very short forecast horizons this leads to a very important increase in forecast accuracy (see Figure 4). Usually NWP model data and online measurement data are combined for the short-term forecast, giving more weight to the NWP data for longer forecast horizons and more weight to online data for shorter horizons. Very short-term forecasts of up to 1 or 2 hours are possible even without NWP model data. For forecast horizons of more than about half a day the online data usually do not add information the NWP model data and the short-term forecast ends.

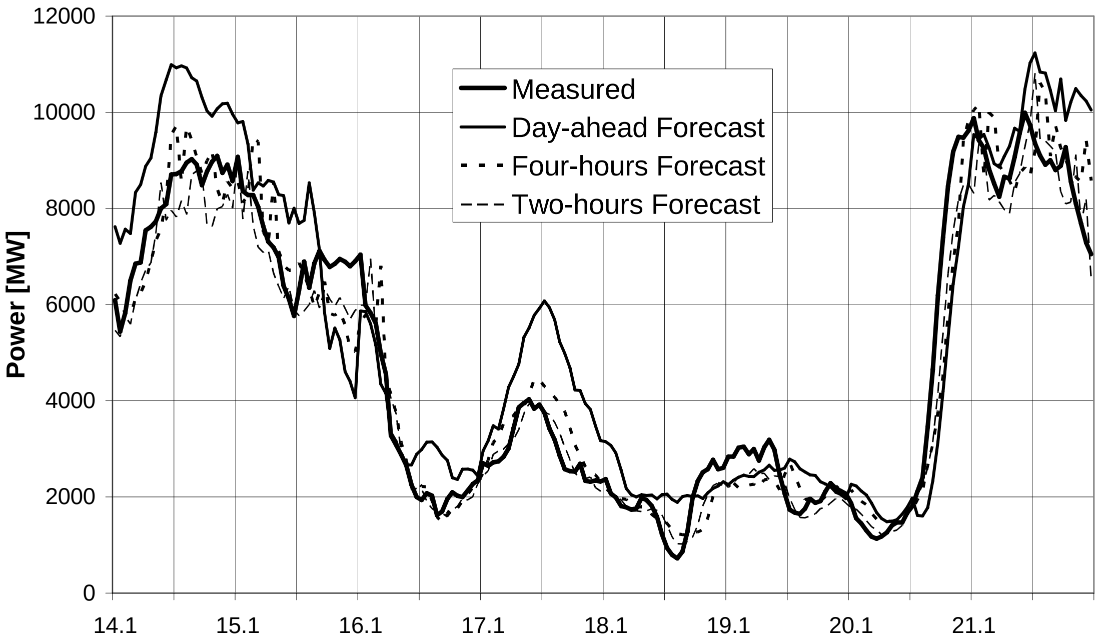


Figure 4: Example time series of online measurement and forecasts of wind power generation in Germany; forecasts with different forecast horizons are shown.

7 Regional upscaling

A wind power forecast for a larger region with many wind farms is usually made by forecasting only some of the wind farms and extrapolating their power output to the whole region - often called regional up-scaling. This minimises the effort involved in making the forecasts and reduces the amount of data needed from NWP models as input. The accuracy of the forecasts does not decrease much, since wind farms close to each other show a similar behaviour. However, it is important that the wind farms selected for forecasting are representative of all wind farms to which their output is extrapolated.

Different algorithms can be used for upscaling. Their main function is to calculate the output of all wind farms of the area from the known - or forecasted - output of the representative wind farms. In the Wind Power Management System (WPMS), developed by ISET in Germany, the following mechanism is used:

The area of interest it is subdivided into grid squares. For each of these grid squares the installed capacity of wind farms, their coordinates and hub heights and the roughness of the terrain are known.

This information is compiled from a data base of all wind turbines in Germany, which includes:

- Installed power
- Rotor radius

- Hub height
- Location
- Turbine type
- Surface roughness
- Date of erection and dismantling

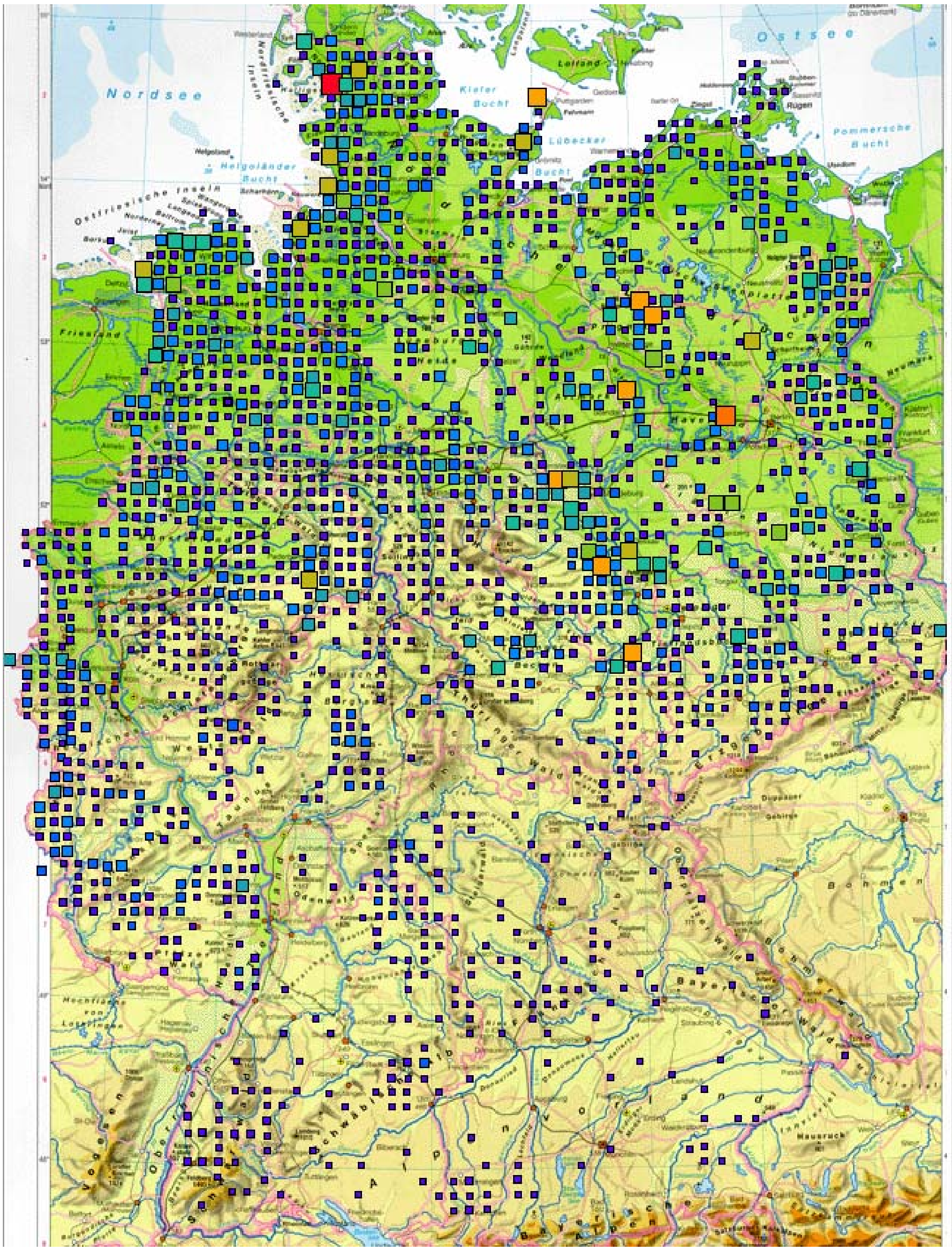


Figure 5: Grid squares used by WPMS for regional up-scaling

Figure 5 shows the grid squares for Germany as an example. The size of the squares shows information about installed capacity (smallest squares 1-13 MW), largest squares 131-146 MW). The WPMS calculates the power output of the wind turbines in each grid square by using the forecast power output of the representative wind farms. The closer a reference wind farm is to the grid square, the greater is its influence (see Figure 6). Considering a case with i grid squares and j representative wind farms, the power output of the whole region P_{total} is the sum of the power output P_i off all grid squares:

$$P_{total} = \sum_i P_i \qquad (1)$$

The power output of one grid square is calculated from the weighted power outputs of all representative wind farms:

$$P_i = k_i \sum_j A_{ij} P_j \qquad (2)$$

Here P_j is the power output of representative wind farm j, normalised with its installed power and k_i is a normalisation factor. The weighting factors A_{ij} are calculated as

$$A_{ij} = \exp\left(\frac{-S_{ij}}{S_0}\right) P_{IP,i} \qquad (3),$$

where $P_{IP,i}$ is the installed power in grid square i, S_{ij} is the distance between representative wind farm and grid square and S_0 is a spatial correlation parameter, which has to be determined empirically.
The normalisation factor k_i makes sure that the sum of all weighing factors equals one.

$$k_i = \frac{1}{\sum_j s_j * A_{ij}} \qquad (4)$$

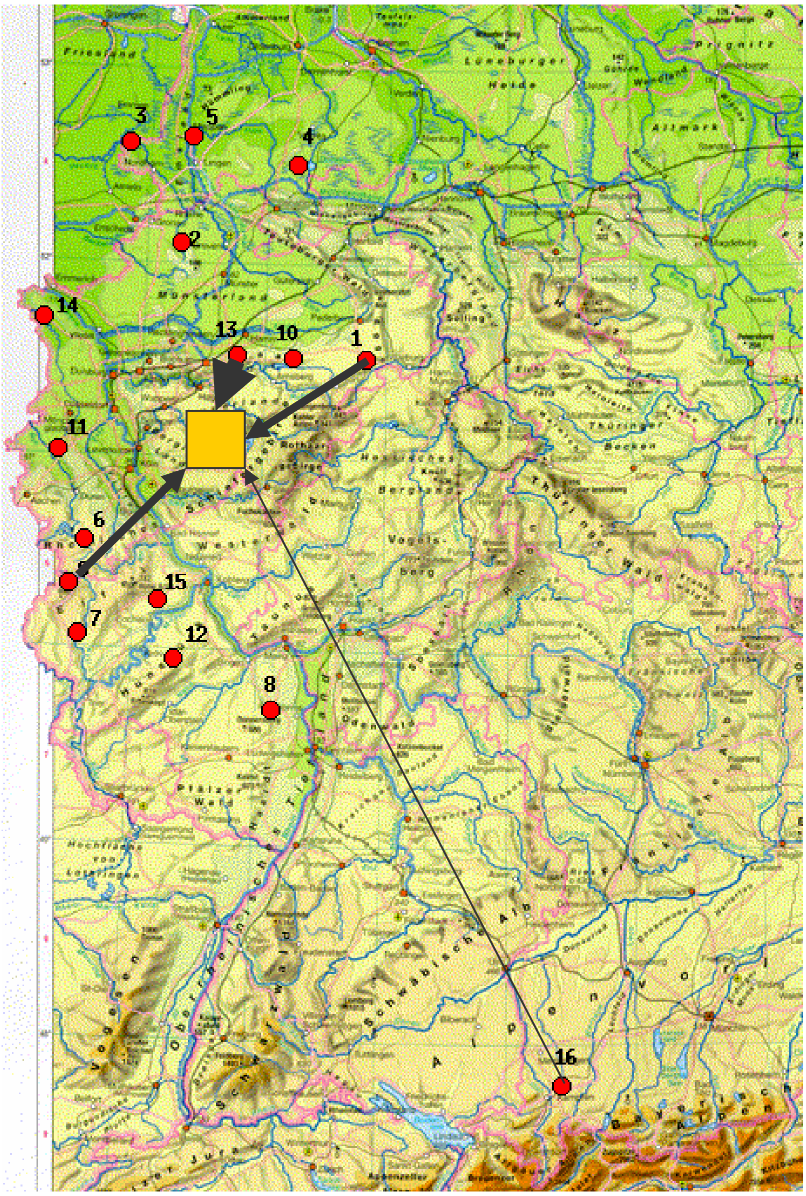


Figure 6: Sketch of the calculation of the power output of a grid square with the up-scaling mechanism

8 Smoothing effect

The power output of wind farms fluctuates. These fluctuations are very difficult to forecast and even if the power output on a particular day is predicted well, the fluctuations will cause a forecast error. The larger the wind farm, the smaller will be the fluctuations and the corresponding forecast error. If many wind farms are forecast together, the forecast error decreases further. And the aggregation of large regions with several GW installed capacity will lead to a decrease in the relative forecast error, since there will be cases where the forecast errors of different regions will partly cancel each other out. An example of this is shown in Figure 7: It shows the forecast error for the three German control zones with large wind power capacity, those of E.ON, VE-T and RWE, together with the error of the aggregated forecast for an example time series of four days. It can be seen that the forecast error for the aggregated wind power always stays below 2,5%, while the error for single control zones reaches up to 8%. The forecast error is given here as the difference between forecast and measurement in percent of the installed capacity.

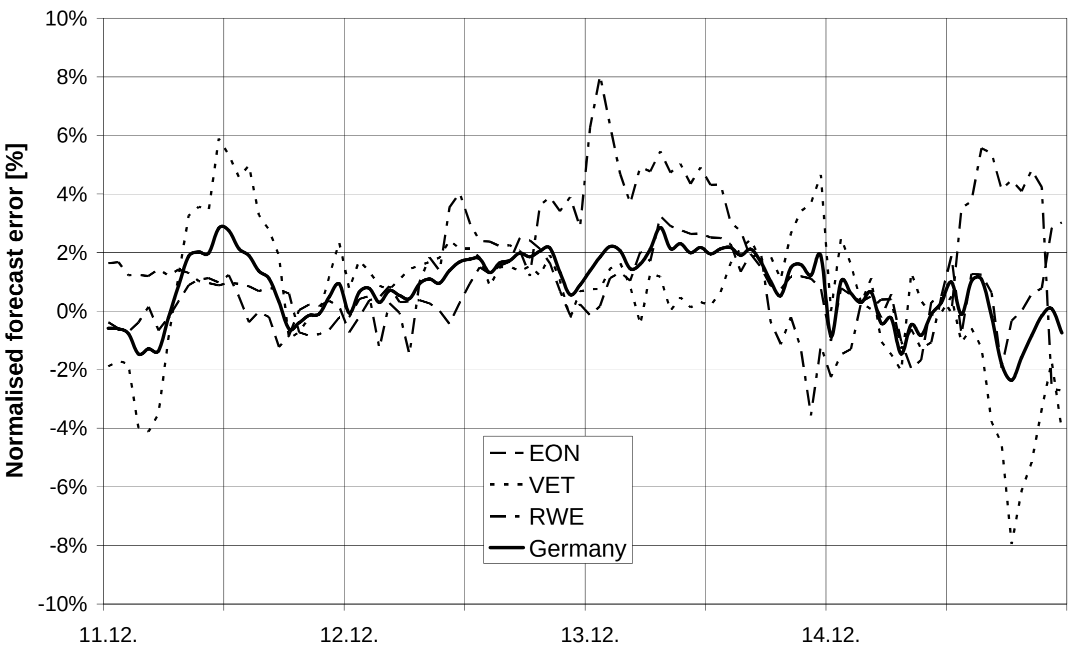


Figure 7: Example time series of relative forecast error for the individual control zones of EON, VET and RWE, and for the whole of Germany

The forecast error depends on the number of wind turbines and wind farms and their geographical spread. In Germany, typical forecast errors for the representative wind farms forecast with WPMS are 10-15% RMSE (root mean square error) of installed power, while the error for the control zones calculated from these representative wind farms is typically 6-7%, and that for the whole of Germany only 5-6%.

9 Forecast accuracy

The accuracy of a wind power forecast is of course the most important criterion for its quality and value. Figure 8 shows an example time series of the day-ahead forecast for Germany together with its monitored values for one month.

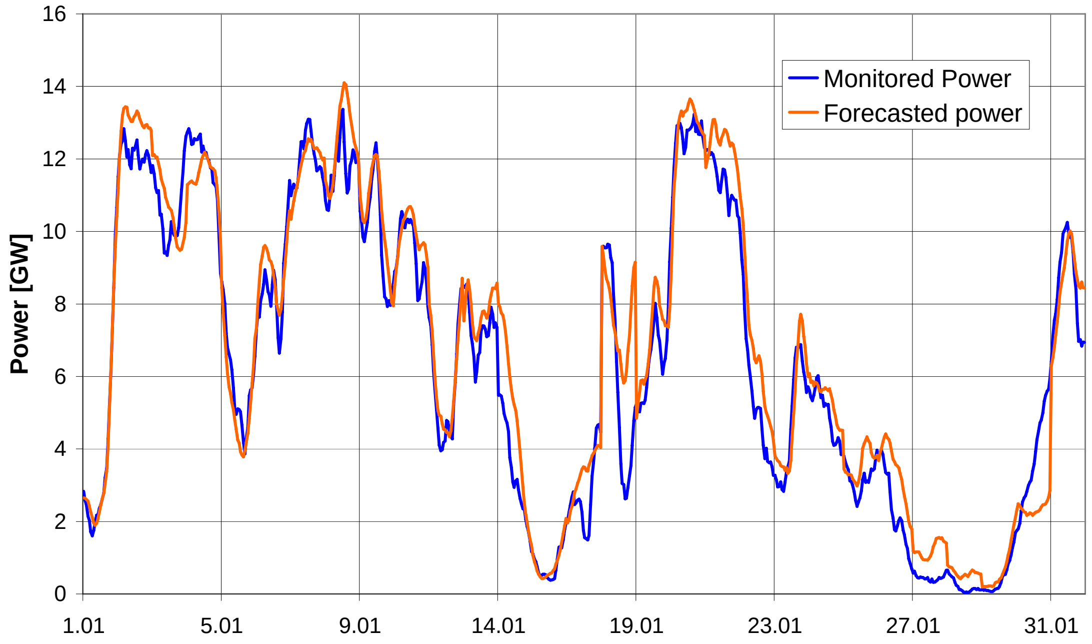


Figure 8: Example time series of monitored and forecast power output for Germany

Since the forecast accuracy changes with time, a long time period has to be considered to evaluate the quality of a forecasting system. Since this is difficult with a time series plot, often a scatter plot is used. However, the information at which time a certain error occurred, is lost in this evaluation method. An example of a scatter plot of forecast errors is given in Figure 9. The forecast wind power output for Germany is shown versus the monitored values. The data comprise the period of one year and are normalised with the installed capacity. The forecast data are from a day-ahead forecast performed with ISET's wind power management system (WPMS) using NWP data from the German weather service (DWD).

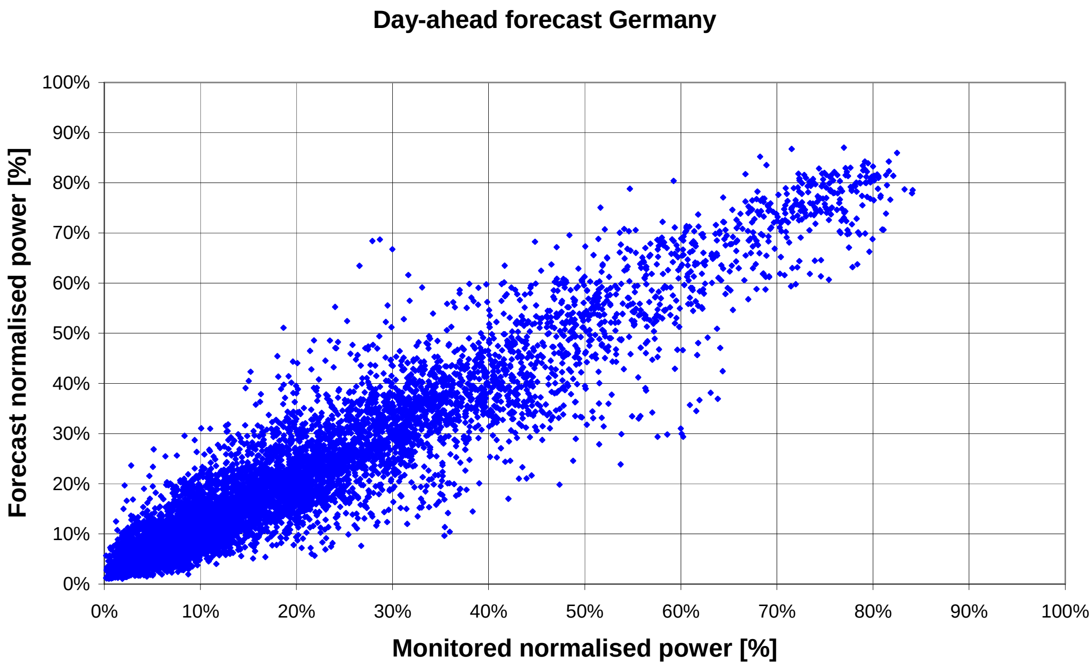


Figure 9: Forecast versus monitored wind power output for Germany; values are normalised with the installed capacity

The information given in the scatter plot can be further condensed by calculating a frequency distribution of the forecast error. Here the information at which power output a certain error occurred is not visible any more. Figure 10 shows an example, using the same data as in the scatter plot.

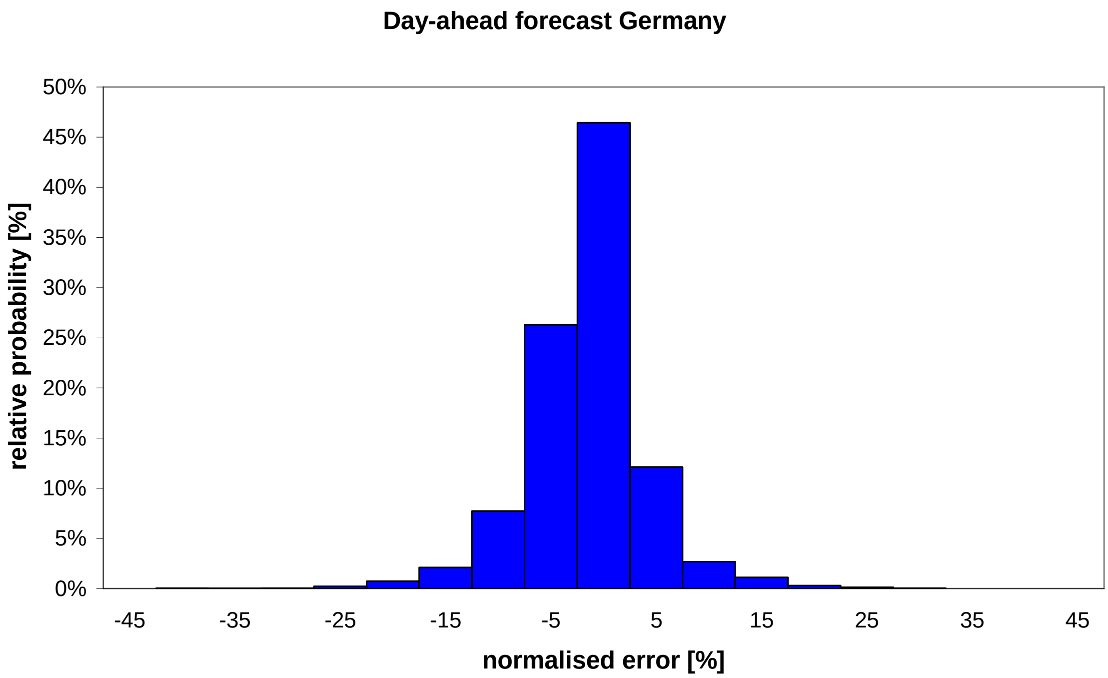


Figure 10: Frequency distribution of the difference between forecast and monitored power output; data as in Figure 9

Often the information about the forecast error needs to be further condensed to only one or a few values. Many different error measures can be used for this:

- BIAS (mean error)
- MAE (mean average error)
- RMSE (root mean square error)
- Correlation coefficient, r

Additionally, different ways of relating the error to the production or size of the installation are used:

- Normalised with installed power
- Normalised with mean power generation
- With respect to current power generation

It has to be stressed that different measures lead to very different values. For comparison of different wind power forecasting systems, it is therefore extremely important to be sure to use the same error measures. Additionally, the error depends on many other influences, which have to be equal for a comparison of different systems:

- The error is different for each wind farm, depending on local conditions, the size and location of the wind farm, geographical spread, etc.
- For regional forecasts, it depends on the number of wind farms, their size and spatial distribution (see section 8)
- The error depends on the weather prediction model used as input.
- It is different for different time periods.
- It depends on the amount and quality of the measured data used as input to the system.
- It also depends on the forecast horizon (see section 6)

10 Example: The Wind Power Management System (WPMS)

Wind power forecasting is an integral part of the electricity supply system in Germany. The Wind Power Management System (WPMS), developed by ISET, is used operationally by three of the four German transmission system operators (see Figure 11). The system consists of three parts:

The online monitoring, which performs an up-scaling of online power production measurements at representative wind farms to the total wind power production in a grid area.

The day-ahead forecast of the wind power production by means of artificial neural networks (ANN). This is based on input from a numerical weather prediction (NWP) model.

The short-term forecast, which additionally employs on-line wind power measurements to produce an improved forecast for up to 8 hours ahead.

For a short-term wind power forecast, representative wind farms or wind farm groups have to be determined and equipped with online measurement technology. For the day-ahead forecast, only historical time series of measured power output of the representative wind farms are needed. For these locations, forecast meteorological data obtained from a numerical weather prediction (NWP) model are used as input. The resolution of the forecast and the forecast horizon depend on the NWP data used. In Germany, currently an hourly resolution and a forecast horizon of 3 days are in operation.

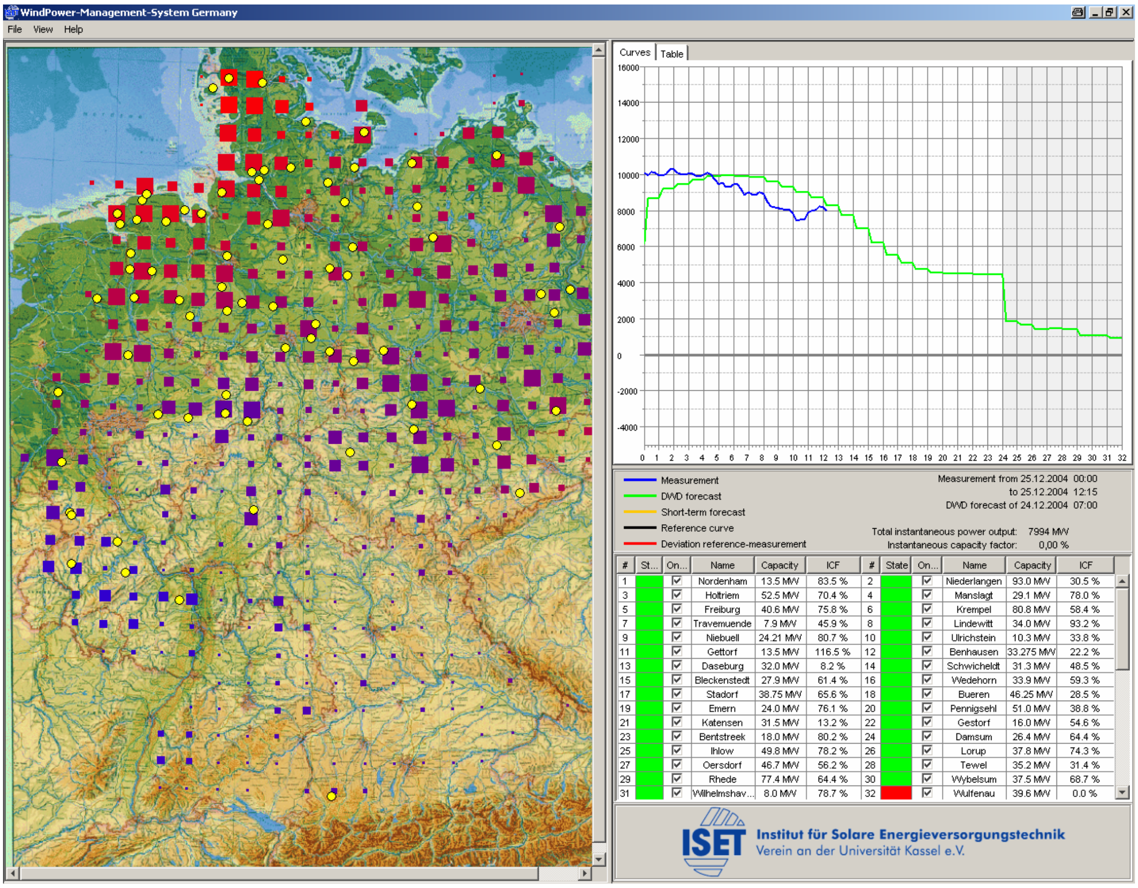


Figure 11: The graphical user interface of the Wind Power Management System (WPMS)

Artificial neural networks (ANN) are used to forecast the wind power generated by a wind farm from the predicted meteorological data of the NWP model. The ANNs are trained with NWP data and simultaneously measured wind farm power data from the past, in order to ‘learn’ the dependence of the power output on predicted wind speed and additional meteorological parameters (Figure 12). The advantage of an artificial neural network over other calculation procedures is that it ‘learns’ connections and ‘conjectures’ results, even in the case of incomplete or contradictory input data. Furthermore, the ANN can easily use additional meteorological data like air pressure or temperature to improve the accuracy of the forecasts. In the operational forecast system, the deviation (Root Mean Square Error, RMSE, as a percent of the installed capacity) between the (day ahead) predicted and actual occurring power for the control areas of ENE, VE-T and RWE currently currently is about 6-7% of the installed capacity. The forecast error for the total German grid amounts to 5-6%.

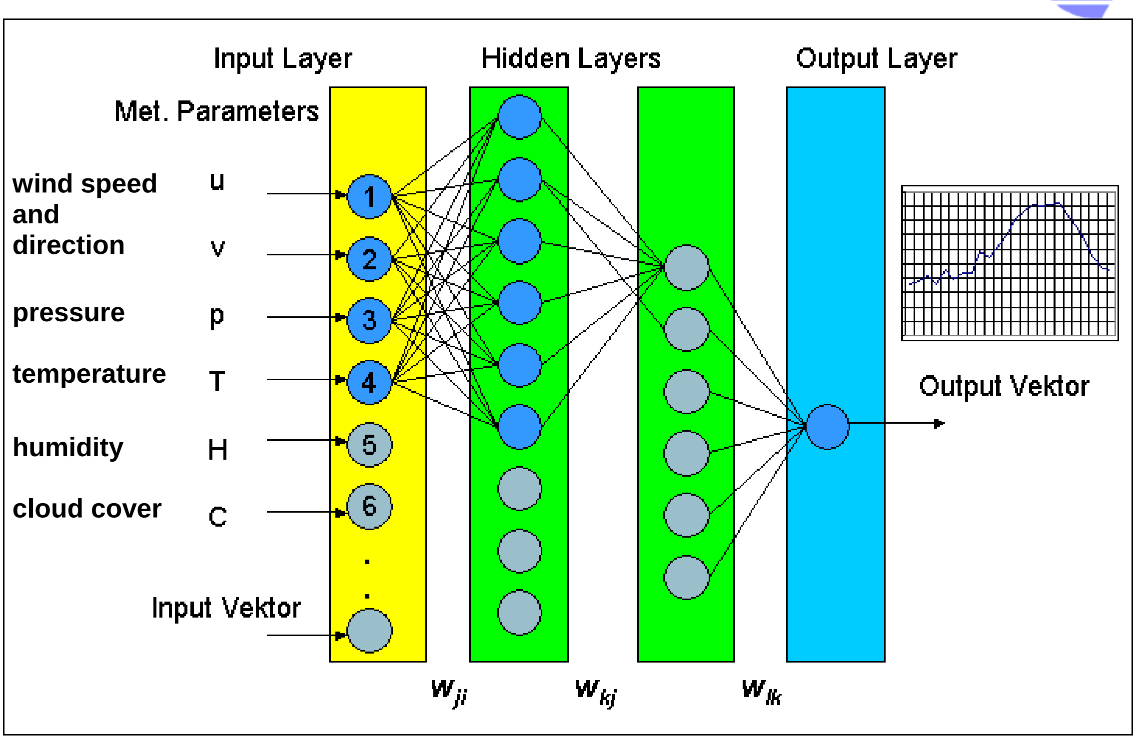


Figure 12: Sketch of an artificial neural network (ANN) used for the wind power forecast

In addition to the forecast of the total output of the wind turbines for the following days (up to 72 hours), short-term (15-minutes to 8 hours) forecasts are the basis for efficient and safe power system management. Apart from the meteorological values such as wind speed, air pressure, temperature etc., online power measurements of representative sites are an important input for the short-term forecasts. As in the day-ahead forecast, ANNs are used to relate the input values to the power output. The forecast uncertainty is considerably lower than for the day-ahead forecast. For the German grid the RMSE as a percentage of the installed capacity is currently 2.6% for the 2-hour-ahead forecast and 3.6% for the 4-hour-ahead forecast [17].

11 'Learning curve' of the forecasting accuracy

Since the WPMS forecasting system was first implemented in 2001, it has been improved constantly. The result is a continuous reduction of the forecast error, resulting in a 'learning curve' of decreasing forecast error over time, as can be seen in Figure 13, which shows the development of the forecasting error for the example of the E.ON control zone [13]. The accuracy of the operational wind power forecast has improved from approximately 10% RMSE at the first implementation in 2001 to an RMSE of about 6.5% in 2005.

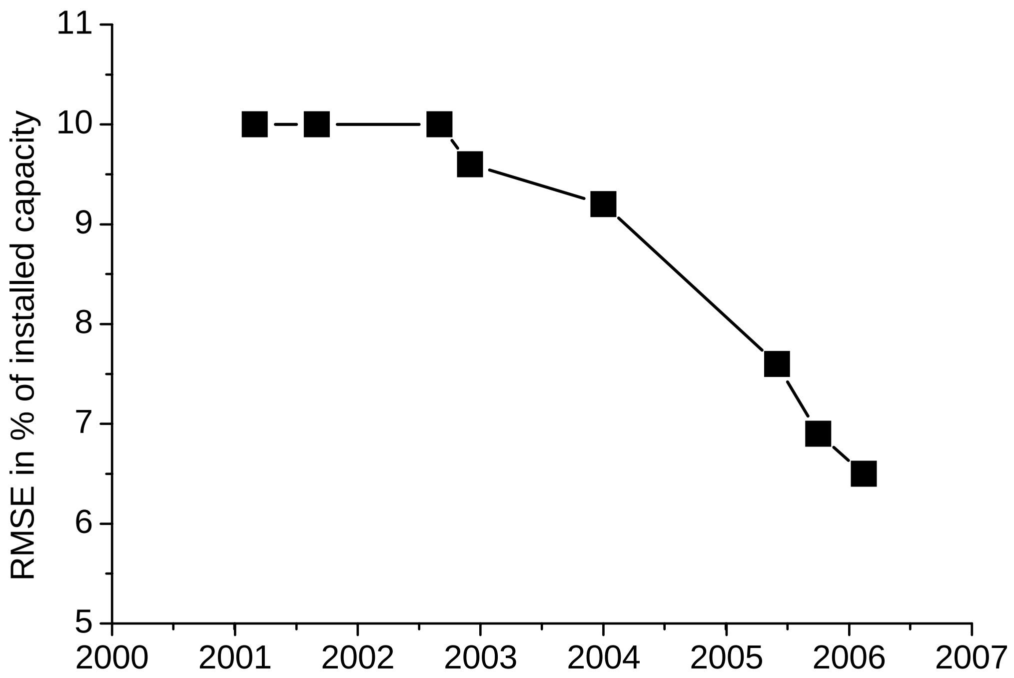


Figure 13: Development of the forecasting error of the operational day-ahead forecast for a control zone; shown is the root mean square error of the forecast time series compared to that of the online monitoring

The operational experience of several years shows that the system has not only performed well in terms of accuracy, but also in terms of practical usability. The system has been installed in three different control room software environments. It has been extended constantly to include user requirements and wishes and now includes e.g. a hot stand-by capability with full monitoring, different options for the graphical user interface, etc.

12 Examples for current research

12.1 Improved representation of the atmospheric boundary layer

The selection of the input parameters for the ANN is of crucial importance for the performance of the forecast. Wind velocity and wind direction are, of course, the most important parameters for the wind power forecast. However, with the neural network approach it is easily possible to incorporate additional parameters. The set of meteorological parameters used for the forecast has been improved to take into account the influence of atmospheric stability, especially for new turbines with high towers. This has led to an important improvement in forecast accuracy. Most important was the inclusion of the wind speed predicted by the NWP at 100 m height [17]. As can be seen in Figure 14 for the example of one German TSO control zone, the forecast error (RMSE as a percent of installed capacity) was reduced by more than 20%. Two different numerical weather prediction models were used as input for the forecast, showing very similar results.

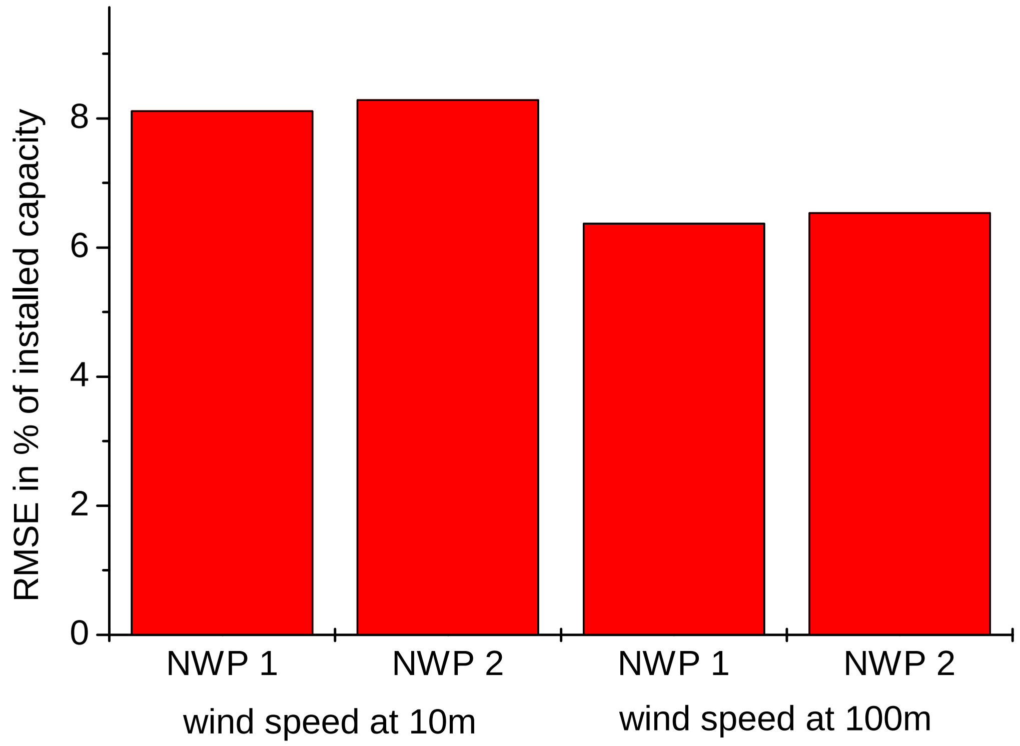


Figure 14: Comparison of the wind power forecast accuracy for a control zone using 10 m and 100 m wind speed as input parameter

12.2 Multi-model approach for forecasting methods

The day-ahead wind power forecast by ANN using one method of artificial intelligence (AI) is used operationally by German TSOs. To improve the forecast ability other types of AI-models were investigated in a comparative study [18]. In detail, these were:

- Artificial neural networks (ANN) as reference
- Mixture-of-experts (ME)
- Nearest-neighbour search (NNS) combined with particle swarm optimization (PSO)
- Support vector machines (SVM). Additionally we built an ensemble including all models.

The ANN consists of nonlinear functions g which are combined by a series of weighted linear filters [19]. Here a neural network with one 'hidden layer' with j 'neurons' was used, constituting the weight matrices A and a.

$$\hat{P}_t = g\left[\sum_{j=1}^{m} a_j g\left(\sum_{k=1}^{m} A_{jk} w_{kt}\right)\right]$$

The vector w_{kt} contains the input data from the numerical weather prediction model, i.e. k values of meteorological parameters at time t. $\hat{P}_t$ denotes the output value, i.e. the predicted power output of a wind farm at the time t.

The ME model is a construction of different 'expert' neural networks to tackle different regions of the data, and then uses an extra 'gating' network, which also sees the input values and weights the different experts corresponding to the input values [20].

The NNS [21] uses those observations in a historical NWP data set closest in input space to the actual input values to form the output. The NNS method used is based upon the construction of a common time delay vector of weather data from several prediction locations of the NWP and upon an iterative algorithm consisting of the NNS and a superior PSO for the selection of optimal input weather data [22].

The SVM maps the input data vectors w_t into a high-dimensional feature space by calculating convolutions of inner products using some so-called support vectors w_i of the input space.

$$f(w_t) = sign\left[\sum_{\sup port \quad vectors} P_i \alpha_i K(w_i, w_t) - b\right]$$

In general, support vector machines are learning machines using a convolution of an inner product K, allowing the construction of non-linear decision functions in the input space, which are equivalent to linear decision functions in the feature space. In this feature space, an optimally separating hyperplane is constructed [23].

A comparative study between the different forecasting methods has been performed using power output measurements of 10 wind farms in the E.ON control zone and corresponding NWP prediction data for these points from the German weather service DWD. Data from September 2000 to July 2003 have been used. Figure 15 shows the comparison of the mean RMSE for the 10 wind farms. It can be seen that the support vector machine yields the best results in this case. Also, a simple ensemble approach has been tested by averaging the outputs of the models studied. As can be seen in Figure 15, even this simple ensemble improves the forecast accuracy compared to the results of the single ensemble members.

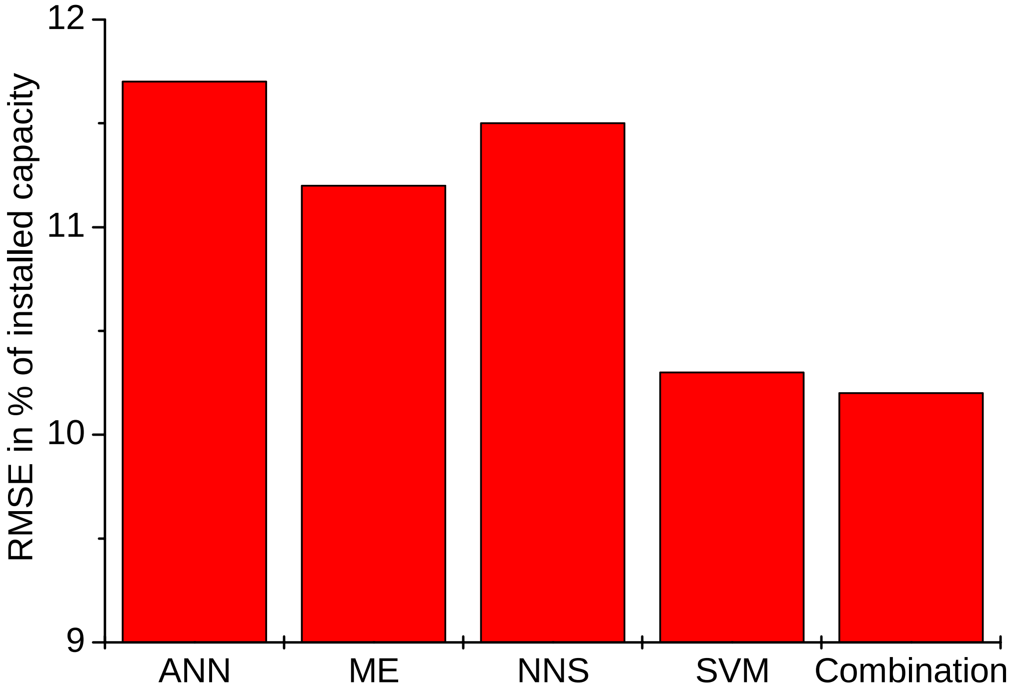


Figure 15*: Comparison of the mean RMSE of a wind power forecast for a group of single wind farms obtained with different AI methods and with a combination of all methods; The methods used are: Artificial neural networks (ANN), Mixture of Experts (ME), Nearest Neighbour Search (NNS) and Support Vector Machine (SVM)*

12.3 Multi-model approach for numerical weather forecast models

A study has been performed to investigate the influence of merging different NWP models on the accuracy of the wind power forecast. Three different NWP models have been used for a day-ahead wind power forecast for Germany (see Table 2). All three models have been used as input to the WPMS based on the ANN method. The training of the networks has been performed with data of more than one year. A concurrent data set of seven months (April – October 2004) has been used for the comparison.
The RMSE in percent of the installed capacity of the three models is shown in Figure 16. It can be seen that the differences between the different models are small. Additionally, a simple combination of the three models has been tested by averaging their forecasts. It can be seen that even this simple approach improves the forecast accuracy very significantly compared to the results of the single models. The resulting RMSE for the combined model for Germany is 4,7%, while the values for the individual forecasts are between 5,8% and 6,1%.

Table 2: Main characteristics of the NWP models used

	NWP-1	NWP-2	NWP-3
Forecast Schedule	72 Hours	48 Hours	72 Hours
Model Runs	00 and 12 UTC (Universal Time)	00 UTC	00 UTC
Available Parameters	Wind Speed Wind Direction Temperature Air Pressure Humidity	Wind Speed Wind Direction Temperature Air Pressure Humidity Momentum Flux	Wind Speed Wind Direction Temperature Air Pressure

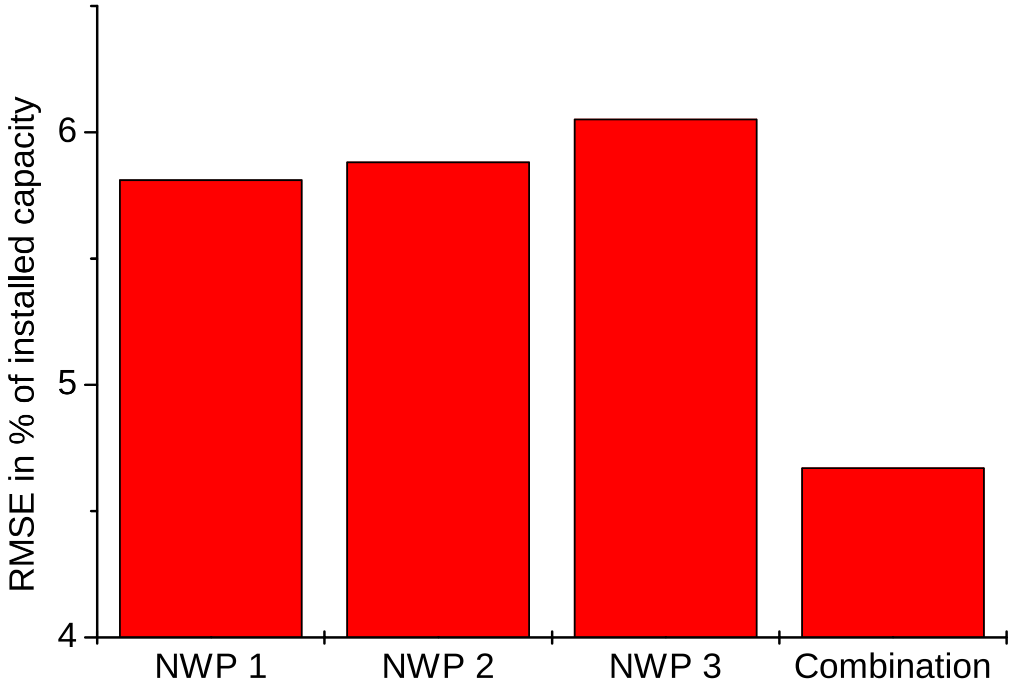


Figure 16: Comparison of the mean RMSE of a wind power forecast for Germany obtained with the WPMS based on ANN with input data from three different NWP models and with a combination of these models

12.4 Prediction of the forecast uncertainty

In addition to the wind power forecast itself, it is important to have knowledge of uncertainties of this forecast. A confidence interval of the forecast gives a quantitative measure of the possible deviation of the actual wind power from the forecast, depending on the meteorological input data for each time stamp. A statistical method has been used to predict not only the power output, but also an upper and lower limit for the forecast accuracy for each time step (Figure 17) [17]. The method is based on the determination of the forecast uncertainty for each representative wind farm, depending on wind speed and wind direction. The total uncertainty is than calculated from the uncertainty estimations of all representative wind farms.

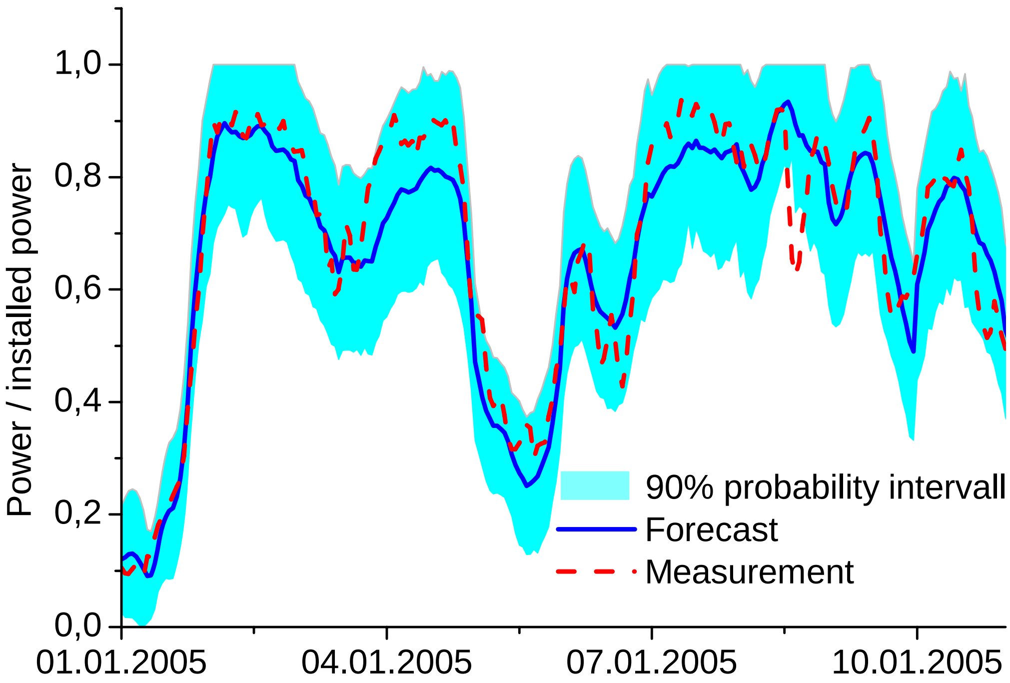


Figure 17: Example time series of the forecast power output and its 90% probability interval, compared with the values of the online monitoring

13 Future challenges

As the wind power capacity grows fast in Germany and many other countries, forecast accuracy becomes increasingly important. Especially for large offshore wind farms, an accurate forecast is crucial due to the concentration of large capacity in a small area. However, in recent years the forecast accuracy has improved constantly, and it can be expected that this increase can be maintained in the future. For the WPMS, a number of improvements are planned:

- The development of operational ensemble model systems using the data from several numerical weather prediction models will clearly improve the forecast accuracy. Also, an improved method for model combination will be developed.
- Improvements in the NWP models and more frequent updates of the weather predictions will improve the input data for wind power forecasting.
- Further improvements in the forecasting methods and improved methods for the combination of different forecasting methods can be expected to further reduce forecasting errors.
- Especially for short-term wind power forecasting, additional use of online wind measurement data has the potential for improved forecasts. In Germany, it is planned to use the ISET wind measurement network [24] to correct the NWP data used for the forecasts.

Forecast accuracy is only one of the challenges for wind power forecasting systems of the future. Additionally, the scope of systems will have to be extended to meet future challenges:

- Wind power forecast in the offshore environment has the potential to become more reliable than on land, if specific offshore forecast models are developed. The meteorological situation in the near-shore marine atmospheric boundary layer differs from that over land. Especially, the atmospheric stability and the distance to the shore have an important influence over sea.
- Improved forecasts for short time horizons will be needed for grid safety and intra-day trading.
- Prediction of the probability distribution of the forecasting error and reduction of events with large errors give the opportunity to reduce the reserve capacity for balancing wind power forecast errors.
- Forecasts in high spatial resolution for each grid node of the high voltage grid will be needed for high wind power penetration, in order to tackle the problem of congestion management.

Acknowledgement

This work on this chapter has been partially funded by the European Commission in the DESIRE (Dissemination strategy on electricity balancing for large scale integration of renewable energy) project (TREN/05/FP6EN/S07.43516/513473). The research described has been partially funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (project No. 0329915A).

References

[1] Doms, G., U. Schättler: ‚The non-hydrostatic limited area model LM (Lokal-Modell) of DWD. Part I: Scientific documentation’. Deutscher Wetterdienst, Geschäftsbereich Forschung und Entwicklung, Postfach 100465, 63004 Offenbach, 1999. (http://www.cosmo-model.org).

[2] Mortensen, N. G., L. Landberg, I. Troen, E. L. Petersen: ‚Wind Atlas Analysis and Application Program (WAsP)’. Risø National Laboratory, Roskilde, Denmark, 1993.

[3] Grell, G.A., J. Dudhia, D.R. Stauffer: ‚A description of teh fifth-generation Penn State/NCAR mesoscale model (MM5). Technical Report NCAR/TN-398+STR, National Center for Atmospheric Research, Boulder, CO, 1994.

[4] PARK [Computer Program]. Risø National Laboratory, Roskilde, Denmark, 1993.

[5] FLaP [Computer Program]. University of Oldenburg, Oldenburg, Germany, 2002

[6] L. Landberg. ‘Short-term Prediction of Local Wind Conditions’. Technical Report Risø-R-702(EN), Risø National Laboratory, 1994.

[7] Landberg, L.: ‘Short-term Prediction of Local Wind Conditions’. *J. Wind Eng. Ind. Aerodyn.* 89, pp. 235-245 (2001)

[8] Focken, U., M. Lange, and H.P. Waldl: 'Previento - a wind power prediction system with innovative upscaling algorithm'. *Proceedings of the European Wind Energy Conference*, Copenhagen, 2001,page 826ff

[9] Focken, U., M. Lange, and H.P. Waldl: 'Previento - Regional wind power prediction with risk control'. *Proceedings of the Global Wind Power Conference*, Paris, 2002.

[10] Nielsen, T.S. and H. Madsen: 'Statistical Methods for Predicting Wind Power'. *Proceedings of the European Wind Energy Conference, Dublin, Ireland, October 1997*, ISBN 0 9533922 0 1, pp. 755-758

[11] Nielsen, T.S., H.A. Nielsen, and H. Madsen: 'Prediction of wind power using time-varying coefficient-functions'. *Proceedings of the XV IFAC World Congress*, Barcelona, 2002.

[12] Rohrig, K., B. Ernst: 'Online-supervision and prediction of 2.500 MW wind power'. *Proceedings of the EWEA Special Topic Conference „Wind Power for the 21st Century", Kassel, 2000*,

[13] Lange, B., K. Rohrig, B. Ernst, F. Schlögl, Ü. Cali, R. Jursa, J. Moradi: 'Wind power forecasting in Germany – Recent advances and future challenges'. *Zeitschrift für Energiewirtschaft*. Vol. 30 no. 2 (2006), pp. 115-120

[14] Landberg, L., G. Giebel, H.Aa. Nielsen, T.S. Nielsen, H. Madsen: ‚Short-term Prediction – An Overview'. Wind Energy 6(3), pp. 273-280, June 2003.

[15] Giebel, G, R. Brownsword, G. Kariniotakis: 'The State-Of-The-Art in Short-Term Prediction of Wind Power. A Literature Overview' Report of the Anemos, project, 2003 (available from: anemos.cms.fr)

[16] Lange, M., U. Focken: Prediction of Wind Power and Reducing the Uncertainty for Grid Operators, Second Workshop of International Feed-In Cooperation, 15-16 Dec 2005, Berlin

[17] ISET: Entwicklung eines Rechenmodells zur Windleistungsprognose für das Gebiet des deutschen Verbundnetzes. Report. ISET e.V., Kassel, Germany, 2005

[18] Jursa, R., B. Lange, K. Rohrig: ‚Advanced Wind Power Prediction with Artificial Intelligence Methods'. Proceedings of the AIESP 2006 - Artificial Intelligence in Energy Systems and Power, Madeira, Portugal, 2006

[19] N. Gershenfeld: *The Nature of Mathematical Modelling*, Cambridge University Press,1999.

[20] C. M. Bishop: *Neural Networks for Pattern Recognition*, Oxford University Press, 1995.

[21] T. Hastie, R. Tibshirani, J. Friedman: *The Elements of Statistical Learning, Data Mining Inference and Prediction*, Springer, 2001.

[22] R. Jursa, B. Lange and K. Rohrig: 'Advanced Wind Power Prediction with Artificial Intelligence Methods', *First International ICSC Symposium on Artificial Intelligence in Energy Systems and Power*, Island of Madeira, Portugal, Feb. 7 – Feb. 10, 2006.

[23] V. N. Vapnik, *The Nature of Statistical Learning Theory*, Second Edition, Springer, 2000.

[24] Hahn, B., M. Durstewitz, R. Döpfer: 'ISET Wind Energy Measurement Network', *European Wind Energy Conference 2006*, Athens

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Sievers, John University of Kassel (UniK)
E-mail	sievers@re.e-technik.uni-kassel.de
Title of dissemination	Speicherung von thermischer Energie zum Ausgleich der Stromerzeugung aus Windenergie
Type of activity	Article
Title of forum	Solarzeitalter
Language	German
Date of dissemination	17.09.2007
Place of dissemination	Germany
Brief abstract / description of dissemination activity	The intention of this article is to present the technical results of the Desire project. Heat stores are a necessary module for balancing wind power fluctuations by the instruments Demand Side Management and Cogeneration. The results were obtained by calculations, which have quantified how far this is possible. Like legislation for instance in Denmark and Germany has shown it is possible to set the right boundary conditions and to then obtain the DESIRED results; in this case a high share of wind power and cogeneration.
Audience impact assessment	Not available yet
Dissemination	Included after this form (Abstract)

SPEICHERUNG VON THERMISCHER ENERGIE ZUM AUSGLEICH DER STROMERZEUGUNG AUS WINDENERGIE

John Sievers, Jürgen Schmid, Mathias Puchta, Stefan Faulstich,
Universität Kassel
Institut für Elektrische Energietechnik
Fachgebiet Rationelle Energiewandlung
Wilhelmshöher Allee 73
34121 Kassel

Tel.: +49 561 804 6206, Fax.: +49 561 804 6434, e-mail: jjsievers@uni-kassel.de

Zusammenfassung
Es zeigt sich, dass es über weite Teile des Jahres möglich ist die Stromerzeugung mit Kraft-Wärme-Kopplung (KWK) von den windstarken auf windschwache Zeiten zu verlagern. Restriktionen treten bei geringem Wärmebedarf im Sommer auf. Wenn gleichzeitig Demand Response, d.h. das Potential der Verschiebung von Stromverbrauchern genutzt wird, ist ein effizientes Stromversorgungssystem mit sehr hohem Windkraftanteil realisierbar.

Ergebnisse aus Untersuchungen im Rahmen des EU-Projekts Desire[1]
Unsere zukünftige europäische Stromversorgung wird aller Voraussicht nach stark mitgeprägt sein von der kostengünstigen Windenergienutzung. Für das europäische Stromnetz bedeutet dies, dass sich zur Variation im Stromverbrauch die variable Stromerzeugung aus Windkraft gesellt. Das zukünftige europäische Stromnetz wird höhere Schwankungen und eine veränderte und veränderlichere Charakteristik zeigen, bei der ständig ein recht plötzlicher Wegfall von Windenergie ebenso wie ein Überangebot auszugleichen ist.
Für eine effiziente Stromerzeugung stehen die Technologien der Kraft-Wärme-Kopplung (KWK) bereit, die bei mittlerer und hoher Netz-Last in Betrieb gehen und sogar Regelenergieaufgaben übernehmen können. Bei diesen Anlagen erfolgt dann neben der Stromnutzung auch eine Wärmenutzung, und je vollständiger die Wärme mitgenutzt wird, umso effizienter ist das Gesamtsystem. Auf der anderen Seite tritt damit eine Restriktion auf den Plan, die dazu führt, dass nur Strom erzeugt werden kann, wenn auch ein aktueller Wärmebedarf vorhanden ist. Ein solches einfaches System wäre stark eingeschränkt in seinen Ausgleichsmöglichkeiten.
Die Erfahrungen aus Dänemark zeigen, dass diese Restriktion für die Stromerzeugung durch den Einsatz von Wärmespeichern und eine geeignete Anlagen-Dimensionierung wegfällt. In West-Dänemark stammt über 50 % aus KWK und über 20 % des Stroms aus Windenergie. Dieser Ausbau-Erfolg ist eng daran geknüpft, dass für KWK eine spezielle Vergütung, der Tripeltarif, mit verlässlichen Rahmenbedingungen eingerichtet wurde. Im Vergleich zu Deutschland wurde hier zu den Spitzenverbrauchszeiten mittags und am frühen Abend ein dritter Tarif mit um ca. 2 ct/kWh_el höherer Vergütung als im Hochtarif bezahlt. Hieraus ergab sich unmittelbar eine extreme Verschiebung auf die hoch vergütete Zeit und eine anders geartete Auslegung als im übrigen Europa. Eine Auslegung mit großen Wärmespeichern gab die für die Stromerzeugung gewünschte Flexibilität, indem Wärme gespeichert und bei Bedarf dem Speicher wieder entnommen wird. Die klaren Randbedingungen auf der einen Seite, und der auch von der Bevölkerung über Beteiligungsmodelle an der Fern- bzw. Nahwärmeversorgung mitgetragene Umstieg auf Kraft-Wärme-Kopplung waren weitere sehr günstige Rahmenbedingungen für einen kräftigen KWK-Ausbau.

[1] http://www.project-desire.org/

Die andere Seite des Windenergie-Ausgleichs, als Ergänzung zur abgestimmten Stromerzeugung mit KWK, ist das Demand Response. Hierbei wird der Betrieb von Stromverbrauchern wie z.B. Wärmepumpen und Kühlaggregaten von Zeiten mit voraussehbarer Unterdeckung auf Zeiten mit „Stromüberschuss“ verlagert. Die Untersuchungen hierzu konzentrierten sich auf solche Verbraucher, die mit geeigneten thermischen Speichern in Verbindung stehen wie z.B. Wärmespeicher für Heizung und Warmwasser sowie Kühlanlagen. Es zeigt sich, dass hier ein erhebliches Potenzial zur sinnvollen Verwendung von Überschussstrom aus Windenergie vorhanden ist.

Fazit

Die Nutzbarmachung von thermischen Speichern kann für das zukünftige europäische Stromnetz mit hohem Anteil erneuerbarer Energien eine Schlüsselrolle übernehmen.

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Peter Ritter, EMD Deutchland
E-mail	pr@emd.dk
Title of dissemination	Flexible KWK-Anlagen können den Bedarf an Regelenergie für den weiteren Ausbau der Erneuerbaren Energien mindern (Flexible CHP plants can reduce the demand for regulating power in the further development of renewable energy)
Type of activity	Article in trade magazine
Title of forum	Energie and Management
Language	German
Date of dissemination	2007
Place of dissemination	Germany
Brief abstract / description of dissemination activity	1. Benefit of flexible CHP with thermal stores and DESIRE. 2. Article with 5000 letters. 3. Dissemination of the benefit of flexible CHP
Audience impact assessment	Not available yet
Dissemination	Included after this form

Flexible KWK-Anlagen können den Bedarf an Regelenergie für den weiteren Ausbau der Erneuerbaren Energien mindern

Peter Ritter, EMD Deutschland, Kassel

Wissenschaftler und Experten aus Europa haben im Rahmen des EU-Projekts DESIRE (www.projekt-desire.org) den Bedarf und die verschiedenen Möglichkeiten untersucht, wie die schwankende Einspeisung aus großen Anteilen von Erneuerbaren Energien ausgeglichen werden kann. Ein besonderer Schwerpunkt mit umfangreichen Analysen und Berechnungen wurde dabei auf die KWK gelegt. Darüber hinaus wurden die Erkenntnisse an konkreten Demonstrationsbeispielen in Dänemark umgesetzt, die Online unter www.emd.dk/desire/skagen bzw. www.emd.dk/desire/hvidesande verfolgt werden können.

Die großen Potentiale der KWK in Deutschland und die umfangreichen Möglichkeiten der CO_2 Einsparungen durch deren Ausbau wurden erkannt und daher soll die Deckung des Stromverbrauchs durch KWK von derzeit 12% auf 25% bis 2020 KWK gesteigert werden. Dennoch werden die positiven Eigenschaften von flexiblen KWK zur Abdeckung der Variation von Angebot und Nachfrage an Strom außer Acht gelassen. Die notwendige Flexibilität erhalten die KWK Anlagen durch die Installation von großen Wärmespeichern, wie sie z.B. in Dänemark schon zu Zeiten des dreistufigen Einspeisetarifs realisiert wurden. Wärmespeicher haben den Vorteil, dass je nach Größe der Speicher die Stromerzeugung vom Wärmebedarf um einige Stunden (z.B. 5-8 Stunden) entkoppelt werden kann. Dadurch können die KWK Anlagen auch heute schon zu Zeiten hoher Preise an der Strombörse den Strom flexibler vermarkten und so Ihre Gewinne maximieren. Dabei liegen die Amortisationszeiten für den Wärmespeicher meist unter 3 Jahre.

Da Strom nicht einfach im Netz speicherbar ist, muss die Stromerzeugung immer dem Verbrauch entsprechen. Während die Lastprofile der verschiedenen Verbraucher weit im Voraus prognostiziert werden können und entsprechen frühzeitig die Strombeschaffung von den Energieversorgern an den Märkten vorgenommen werden kann, haben die Erneuerbaren Energien, besonders die Windenergie den Nachteil, dass die zu erwartenden Energiemengen nur kurzfristig vorausgesagt werden können. Daher spielt die Strombörse mit ihrem Handel in der Regel einen Tag im Voraus eine wichtige Rolle. Wie DESIRE und andere Untersuchungen aufzeigen, beeinflusst die für den Folgetag prognostizierte Menge an Windenergieeinspeisung den Preis an der Strombörse. In Dänemark, wo die Windenergieanlagenbetreiber ihren Strom an der Strombörse für 0€/MWh anbieten müssen, damit sie diesen auch sicher einspeisen können, ist der Einfluss besonders deutlich. Teilweise kommt es sogar zu einer 100%iger Abdeckung des Stromverbrauchs durch die Windenergieanlagen, wodurch der Preis dort durchaus auf 0€/MWh fallen kann.

Da die KWK-Anlagen, bedingt durch die Treibstoff- und Betriebskosten, ihren Strom nicht so billig wie Windenergieanlagen anbieten, schützt so die Strombörse zum einen vor Übereinspeisung ins Stromnetz und zum anderen wird der KWK-Betreiber seine Energie nur zu Hochpreiszeiten, wenn der Energiebedarf besteht, einspeisen. Die Strombörse bewährt sich daher als Indikator, wieviel Energie aus Windenergie ins Netz eingespeist und wieviel Energie benötigt wird. So kann Sie als Marktinstrument für die optimale Ausbalancierung des Angebot und der Nachfrage des Stroms bei gleichzeitiger Einspeisung großer Anteile von Erneuerbaren Energien verwendet werden. Leider ist die Strombörse nicht vor Missbrauch geschützt und durch die bestehenden Rahmenbedingungen wie Treibstoffpreise und zu niedrigen Preise für die CO2-Zertifikate, können die Strompreise dauerhaft an der Börse unter den Grenzpreis der KWK-Anlagen fallen, wodurch diese dann den Wärmebedarf mit Kessel abdecken müssen. Für diese Fälle fehlen Gesetze, Fördermodelle und Richtlinien, die den Betrieb und die Investitionen von KWK-Anlagen langfristig absichern.

Die Herausforderung für die Politik besteht nun darin Rahmenbedingungen ähnlich wie durch das EEG zu schaffen, die nicht nur langfristig die Wirtschaftlichkeit der geplanten KWK in Konkurrenz zu den Großkraftwerken ermöglichen, sondern durch Integration von großen Wärmespeichern auch die für den Ausbau der Erneuerbaren Energien erforderliche Flexibilität der KWK-Anlagen sicherstellen. Dadurch können neben der CO2-Einsparung durch Kraft-Wärme-Kopplung weitere volkswirtschaftliche Kosten eingespart werden, da auf einen Teil der Investitionen für zusätzliche Wasser,- und Druckluftspeicherkraftwerke verzichtet werden kann.

In Dänemark wurde im Rahmen des Projekts DESIRE noch einen Schritt weiter gedacht, wie die KWK Anlagen noch flexibler und wirtschaftlicher betrieben werden können. Dazu können die motorbetriebenen KWK-Anlagen am Regelenergiemarkt ähnlich dem Deutschen Intradaymarkt ihre positive und negative Leistung anbieten. Darüber hinaus zeigt sich in Dänemark, dass der Wärmebedarf in Niedrigpreiszeiten an der Strombörse durch Wärmepumpen als Stromverbraucher erzeugt werden kann.

Wie sich in dem Projekt DESIRE gezeigt, hat ergänzen sich die Erneuerbaren Energien und flexible KWK sehr gut. Nun gilt es nun die Hemmnisse für die Investitionen in die KWK zu reduzieren und Anreize für die Investition in große Wärmespeicher zu geben.

Dissemination strategy on Electricity balancing
DESIRE
large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Peter Ritter, EMD Deutchland
E-mail	pr@emd.dk
Title of dissemination	Flexible KWK-Anlagen können einen Teil der für den weiteren Ausbau der Erneuerbaren Energien erforderlichen Regelenergie abdecken (Flexible CHP plants can cover a share of the demand for regulating power in the further development of renewable energy)
Type of activity	Article in trade magazine
Title of forum	Sonne Wind und Wärme
Language	German
Date of dissemination	2007
Place of dissemination	Germany
Brief abstract / de-scription of dissemina-tion activity	1. Benefit of flexible CHP with thermal stores and DESIRE. 2. Article with 17700 letters 1 table and 7 figures . 3. Dissemination of the benefit of flexible CHP
Audience impact assessment	Not available yet
Dissemination	Included after this form

Flexible KWK-Anlagen können einen Teil der für den weiteren Ausbau der Erneuerbaren Energien erforderlichen Regelenergie abdecken

Peter Ritter, EMD Deutschland, Kassel

Überblick

Durch den geplanten weiteren Ausbau der Energieversorgung mit Erneuerbaren Energien (besonders Windenergie) besteht Bedarf an einer Flexibilisierung der Energieversorgung in Europa. Bisher besteht überwiegend die Auffassung, dass dies nur durch den Ausbau der Regelenergiereserven mit modernen großen Kraftwerken (z.B. Gasturbinen) und durch neue Speicherkraftwerke (z.B. Druckluftspeicher) realisiert werden könne. Im Rahmen des Europäischen Demonstrationsprojekts DESIRE (Dissemination strategy on Electricity balancing for large-Scale Integration of Renewable Energy www.projekt-desire.org) mit Projektpartner aus Dänemark, Deutschland, Großbritannien, Spanien, Polen und Estland wurde aufgezeigt, dass es andere Möglichkeiten und Technologien für den Ausgleich von Erzeugung und Verbrauch gibt, die gleichzeitig die Energieeffizienz erhöhen und den CO2 – Ausstoß reduzieren. Einen besonderen Stellenwert erhalten dabei flexible Kraftwärmekopplungs-Anlagen (KWK) mit kurzen Anfahrzeiten und geringen Startkosten in Verbindung mit großen Wärmespeichern. Daher stellen die KWK-Anlagen mit Wärmespeichern neben ihren hohen Energienutzungsgraden eine optimale Ergänzung zu dem Ausbau der Erneuerbaren Energien dar.

Gleichzeitig zeigt sich, dass innerhalb der bestehenden Strukturen des Liberalisierten Strommarkts mit Strombörsen und Regelenergiemärkten auch die Wirtschaftlichkeit von KWK-Anlagen durch den Einsatz von den Wärmespeichern auch in Deutschland erheblich gesteigert werden kann.

Im Rahmen des Projekts DESIRE wurden an konkreten KWK-Beispielen in Dänemark, Deutschland und Großbritannien die Möglichkeiten für einen wirtschaftlicheren Betrieb aufgezeigt. Dazu wurden die Beispiele mit allen Randbedingungen mit der Software EnergyPro von EMD International A/S nachgebildet und die wirtschaftlichste Größe der Wärmespeicher ermittelt. Weiterhin wurde für den optimalen Betrieb von KWK-Anlagen mit Wärmespeicher im liberalisierten Strommarkt in dem Projekt das Softwaretool EnergyTRADE entwickelt. An zwei der dänischen KWK-Kraftwerke wird EnergyTRADE bereits erfolgreich eingesetzt.

In einem weiteren Schritt des Projekts wurde analysiert, inwiefern durch die Teilnahme der KWK-Anlagen an den anderen Strommärkten, wie dem Regelenergiemarkt (z. B. Minutenreserve) und dem Intraday-Markt eine zusätzliche Gewinnsteigerung möglich ist.

Ausgleich von Schwankungen bei Einspeisung großer Anteile von Erneuerbaren Energien

Derzeit spielt die Windenergie in Europa aufgrund seiner geringen Erzeugungskosten die größte Rolle unter den erneuerbaren Energien und soll daher weiterhin umfangreich ausgebaut werden. Die Windenergieeinspeisung hat jedoch den großen Nachteil, dass die Einspeisung entsprechend dem Windangebot variiert und sich nicht mit den Schwankungen der Stromverbraucher deckt (siehe Abb. 1 blaues Band). Dabei können die Lastprofile (oberste Linie Abb. 1) der Verbraucher unter Berücksichtigung der üblichen Temperaturschwankungen über das Jahr, den Feiertagen und Wochenabläufen gut prognostiziert werden. Die Stromerzeugung aus Wind ist jedoch nur ab ca. 48 Stunden im Vorfeld gut prognostizierbar und wird immer besser je kürzer der Vorhersagedauer wird. Dies hat zur Folge, dass bei Windstille Kraftwerksreserven zur Verfügung stehen müssen die den Verbrauch dann abdecken, aber bei windstarken Zeiten nicht benötigt werden. Derzeit ist der Anteil an Windenergie in Deutschland noch gering und zusätzliche Regelreserven wurden nicht benötigt, da die Schwankungen der Verbraucher über den Wochenablauf überwiegen.(siehe Abb. 1) und Reserven für einen Großkraftwerksausfall vorgehalten werden müssen. Der Aufruf der Reserven hat jedoch durch die Windenergienutzung zugenommen. Bei dem geplanten weiteren Ausbau, ähnlich wie in Dänemark, wo der Stromverbrauch durch die Windenergie zeitweise mit über 100 % abgedeckt wird, werden neue Anforderungen an das Versorgungssystem gestellt. Entgegen der verbreiteten Auffassung, dass diese Probleme nur mit neuen Reservekraftwerken und Speicherkraftwerken gelöst werden können, wurden die Energieversorgung in Dänemark mit einen Anteil von über 50% aus KWK-Anlagen mit Hilfe der Marktinstrumente Strombörse und Regelenergiemarkt flexibilisiert.

Strombörse und Regelenergiemarkt als Indikator für Stromangebot und Stromnachfrage

Die Flexibilisierung der Energieversorgung wurde in Dänemark dadurch erreicht, dass die Wind- und KWK-Anlagenbetreiber ihren Strom an der Strombörse verkaufen. Windenergieanlagen bieten einen Tag im Voraus mit prognostizierten Energiemengen ihren Strom für 0 €/MWh an der Strombörse an und erhalten den an der Strombörse ermittelten Preis. Dadurch beeinflussen die Windenergieanlagen in DK im Gegensatz zu Deutschland den Preis an der Strombörse erheblich. Dies kann dazu führen, dass der Preis sogar bis auf 0 € fällt. Da die KWK-Anlagen, bedingt durch die Treibstoff- und Betriebskosten, ihren Strom nicht so billig wie Windenergieanlagen anbieten, schützt so die Strombörse zum einen vor Übereinspeisung ins Stromnetz und zum anderen wird der KWK-Betreiber seine Energie nur zu Hochpreiszeiten einspeisen, also genau dann wenn der Energiebedarf besteht. Die Strombörse bewährt sich dort als Indikator, wieviel Energie aus Windenergie ins Netz eingespeist und wieviel Energie benötigt wird. So kann Sie als Marktinstrument für die optimale Ausbalancierung des Angebot und der Nachfrage des Stroms bei gleichzeitiger Einspeisung großer Anteile von Erneuerbaren Energien verwendet werden. Leider ist die Strombörse nicht vor Missbrauch geschützt und durch die bestehenden Rahmenbedingungen wie Treibstoffpreise und zu niedrigen Preise für die CO2-Zertifikate, können die Strompreise dauerhaft an der Börse unter den Grenzpreis der KWK-Anlagen fallen, wodurch diese dann den Wärmebedarf günstiger mit dem Kessel abdecken müssen.
Im Vergleich besteht in Deutschland derzeit nur ein geringerer Zusammenhang zwischen der Energieeinspeisung aus Erneuerbaren Energien und dem Strompreis an der Strombörse (siehe Abb. 2), da die Übertragungsnetzbetreiber (ÜNB: EnBW Transportnetze AG, E.ON Netz GmbH, RWE Transportnetz Strom GmbH, Vattenfall Europe Transmission GmbH) die Energie aus erneuerbaren Energien, die nach dem Erneuerbaren Energien Gesetz (EEG) vergütet werden, zu einem Tagesband (konstanter Betrag für 24h) veredeln. Der zu erwartende Anteil der Windenergie wird dabei von den ÜNB mit Hilfe des Prognosemodells vom Institut für Solare Energieversorgungstechnik e.V. (ISET) zu festen Uhrzeiten bis zu 48 Stunden im Voraus berechnet. Die Beschaffung und Verkauf der Strommengen zur Veredlung der Energie aus den EEG-Anlagen ist derzeit sehr undurchsichtig und wird überwiegend über bilaterale Verträge abgedeckt. Aufgrund des Tagesbands sind in Deutschland die Strompreise an der Börse im Tagesverlauf nur geringfügig von der Einspeisung durch Erneuerbaren Energien abhängig und sind im Wesentlichen von der Nachfrage geprägt.

Jedoch für eine Flexibilisierung der Energieversorgung zu Gunsten der Einspeisung großer Anteile aus Erneuerbaren Energien mit höherer Energieeffizienz und weniger Kraftwerksreserven zum Ausgleich des schwankenden Stromangebots ist ein Indikator wie der Strompreis für die Einspeisung aus Erneuerbaren Energien notwendig, um dynamische Anreize entsprechend dem Angebot und der Nachfrage für die die Marktteilnehmer zu geben. So lassen sich das Angebot und die Nachfrage an Strom besser aufeinander abstimmen und neue Technologien zur Ausbalancierung können sich entwickeln. Eine weiterer richtiger Schritt zur Flexibilisierung des Strommarkts in Deutschland ist der seit September 2006 eingeführte Intraday-Stromhandel in dem Energiemengen derzeit 75 Minuten und später 45 Minuten vor der Lieferung über die Strombörse EEX gehandelt werden können. Durch den Intraday-Markt kann der Bedarf an Regelenergie für die Windenergieeinspeisung weiter reduziert werden, da der Prognosefehler der Windenergieprognose bei kürzerer Vorhersagedauer wesentlich abnimmt und dann die Energiemengen auf dem Intraday-Markt beschafft bzw. verkauft werden können.

Neue wirtschaftliche Potentiale für KWK-Anlagen

Viele KWK-Anlagen werden in Deutschland neben den je nach Alter, Typ und Größe festgelegten Zuschlägen mit dem an der Strombörse quartalsweise ermittelten „üblichen" Preis vergütet (siehe Abb. 3 rote Linie). Wird der übliche Preis mit den Preisen an der Strombörse verglichen (siehe Abb. 3, blaue Linie) zeigt sich für KWK-Anlagen, die nicht permanent betrieben werden, welcher zusätzliche Gewinn erwirtschaftet werden kann, wenn sie nur zu Zeiten mit hohen Strompreisen an der Strombörse ins Stromnetz einspeisen. So wäre zum Beispiel im 1. Quartal 2006 gegenüber dem üblichen Preis eine Ertragssteigerung von 22% für eine KWK-Anlage mit 65% Auslastungsdauer möglich gewesen (siehe Abb. 3, gestrichelte Linie).

Die entscheidende Größe bei KWK-Anlagen für die optimale Vermarktung an der Strombörse ist der Grenzpreis, der für jede KWK-Anlage individuell zu ermitteln ist. Dieser gibt an für welchen Preis der Strom an der Strombörse verkauft werden muss, damit es billiger ist den Wärmebedarf mit der KWK-Anlage gegenüber dem Kessel zu erzeugen. Dazu werden der thermische und elektrische Wirkungsgrad, alle zusätzlichen Kosten, Einnahmen und Vergünstigungen der KWK-Anlage gegenüber dem Kessel berücksichtigt. Der Grenzpreis berechnet sich für die MWh elektrisch erzeugten Strom aus dem KWK-Bonus, der Steuerersparnis bei Gas und Strom sowie den vermiedenen Netznutungsgebühren die den KWK-Anlagen wegen ihrer dezentralen Einspeisung gutgeschrieben werden (siehe Tabelle 1). Bei der Vermarktung des KWK-Stroms an der Strombörse gibt es dann auch Zeiträume, in denen der Betrieb inkl. Brennstoffeinkauf teurer ist als der Erlös aus Strom- und Wärmeverkauf. Ist dann in dem Wärmespeicher keine Energie mehr zur Verfügung, dann ist es wirtschaftlicher die benötigte Wärme mit Kesseln zu erzeugen. Für Dänemark wurde in DESIRE für diese Fälle bei niedrigen Strompreisen weiterführend untersucht, inwiefern Wärmepumpen als Ergänzung zu den KWK-Anlagen die Wärmeerzeugung übernehmen können. So wird das KWK-Kraftwerk noch flexibler und kann neben der Stromerzeugung auch Strom verbrauchen.

Um den Strom flexibel nur zu Zeiten mit hohen Strompreisen in das Netz einspeisen zu können, aber dennoch den Wärmebedarf abdecken zu können, werden die KWK-Anlagen mit großen Wärmespeichern ausgerüstet. Die wirtschaftlichste Größe des Wärmespeichers ist individuell z.B. mit der Software EnergyPRO von EMD International A/S zu ermitteln, liegt aber üblicherweise in der Größenordnung von 6-8 Stunden Wärmespeicherung des normalen Wärmebedarfs. Die Software ermittelt auf Basis von Zeitreihen unter Berücksichtigung der Spotmarkt Preise, des Wärmebedarfs, des Grenzpreis und verschiedenen Anlagensteuerungstrategie die wirtschaftlichste Speicherkapazität des Wärmespeichers der KWK-Anlage. Für den optimalen Betrieb sind zusätzliche Softwaretools wie EnergyTrade (EMD) notwendig, die unter Berücksichtigung der aktuellen Betriebszustände wie Verfügbarkeit der Anlage, Wärmeinhalt des Speichers, zu erwartendem Wärmebedarf und prognostiziertem Strompreis vorausschauend für eine Woche die Zeiten und Strommenge für die Angebotsabgabe an der Strombörse ermittelt (siehe Abb.4).

Da KWK-Anlagen meist zu klein sind, um den organisatorischen Aufwand und die Bedingungen für den Handel an der Strombörse zu erfüllen, müssen mehrere Anlagen gebündelt werden. Durch das Bündeln (Pooling) von mehreren Kraftwerken zu „virtuellen" Kraftwerken können die Voraussetzungen für diese neue Betriebsstrategie für KWK-Anlagen erfüllt werden (siehe Abb.5). Je nach Größe der Anlagen sind noch elektronische System notwendig, die ein Monitoring und eine Fernbedienbarkeit ermöglichen.

In Dänemark werden im Rahmen von DESIRE das Pooling und der Handel mit Hilfe von EnergyTrade bereits durchgeführt und zeigt sehr gute Erfolge. Der Betrieb kann online im Internet unter www.emd.dk/desire/skagen und www.emd.dk/desire/hvidesande verfolgt werden (Siehe Abb. 6 und 7). Um die Wirtschaftlichkeit der KWK-Anlagen noch weiterhin zu steigern, werden die Anlagen zusätzlich künftig noch Regelenergie an dem Intraday Markt anbieten. Zeitlich liegt die Angebotsrückmeldung von der Strombörse soweit im Voraus, dass danach noch Energie auf dem Intraday Markt angeboten werden kann. Nach der Rückmeldung ob der Betreiber an der Strombörse gewonnen hat oder nicht, kann er dann entsprechend negative Energiemengen (Einschalten der Anlage) oder positive Energiemengen (Abschalten der Anlage) anbieten.

Eine weitere Einnahmequelle für KWK-Anlagen, die z.B. im Sommer aufgrund des geringen Wärmebedarfs nicht benötigt werden, ist der Regelenergiemarkt mit der Minutenreserve. KWK-Anlagen, die Innerhalb von 15 Minuten für mindestens 4 Stunden betrieben werden können dort Ihre Leistungsreserve vermarkten. Um Minutenreserve anbieten zu können müssen jedoch mehrere KWK Anlagen gebündelt (min. 15MW) werden und über einen zugelassenen Händler täglich angeboten werden Auch hierfür ist eine Bündelung und ein Händler notwendig. Bisher ist in Deutschland der Arbeitspreis für die Minutenreserve so teuer, dass die verantwortlichen ÜNB lieber auf die Sekundäre Regelenergie zurückgreife. Dadurch ist der Abruf der Minutenreserve sehr selten und die Anlagen können nur durch ihre Präsenz zusätzliche Einnahmen generieren.

Fazit

KWK Anlagen werden durch die Installation von Wärmespeicher flexibler und können die variierende Einspeisung der Erneuerbaren Energien mit Ausgleichen. Daher ergänzen sich flexible KWK Anlagen geradezu mit den Erneuerbaren Energien und reduzieren den Regelenergiebedarf. In Dänemark mit hohen Anteilen an Einspeisungen von KWK und Windenergieanlagen wird dies bereits praktiziert. Um die Vorteile der flexiblen KWK-Anlagen zu fördern müssen diese in den Strommarkt integriert werden. Eine Integration kann wie in Dänemark über die Strombörse erfolgen. Der Strompreis arbeitet als Marktinstrument, das neben der Stromnachfrage auch die Einspeisung der Erneuerbaren Energien wieder gibt. Da der umfangreiche Ausbau sowohl der Erneuerbaren Energien als auch der KWK politisch umgesetzt werden soll und in Deutschland bis 2020 rund 40 GW neue Kraftwerke benötigt werden, ist es derzeit der richtige Moment die KWK auch gleich „flexibel“ auszubauen.

Welche Potentiale sich in Deutschland zu den flexiblen KWK-Anlagen ergeben und wie viel an Regelenergiebedarf eingespart werden kann, ist noch genauer zu ermitteln. Bisher erfolgte der Ausbau der KWK nicht wie politisch geplant. Gründe liegen in verschiedenen Hemmnissen und Risiken bei der Investition in die KWK. Um einen ähnlichen Erfolg wie bei den Erneuerbaren Energien zu erreichen, sind Gesetze, Fördermodelle und Richtlinien zu erarbeiten, die den Betrieb und die Investitionen von KWK-Anlagen langfristig absichern. Darüber hinaus sind mit Hinblick auf den Ausbau der Erneuerbaren Energien Anreize für die Investition in Wärmespeicher zu geben. Gegen flexiblen KWK Derzeit widerspricht jedoch der gefordert Nutzungsgrad von über 70% für Anlagen bis 2MW für die Gassteuererstattung der Flexibilisierung der KWK-Anlagen und sollte daher Aufgehoben werden.

Auf Basis unserer Untersuchungen verschiedener KWK-Anlagen in Deutschland sind große Wärmespeicher bei Vermarktung des Stroms an der Strombörse wirtschaftlich zu betreiben. Das Projekt DESIRE zeigt die Notwendigkeit der Flexibilisierung der Stromerzeugung und des Stromsverbrauchs auf und hat den Anspruch die Umsetzung Anzustoßen bzw. weiter voran zu treiben

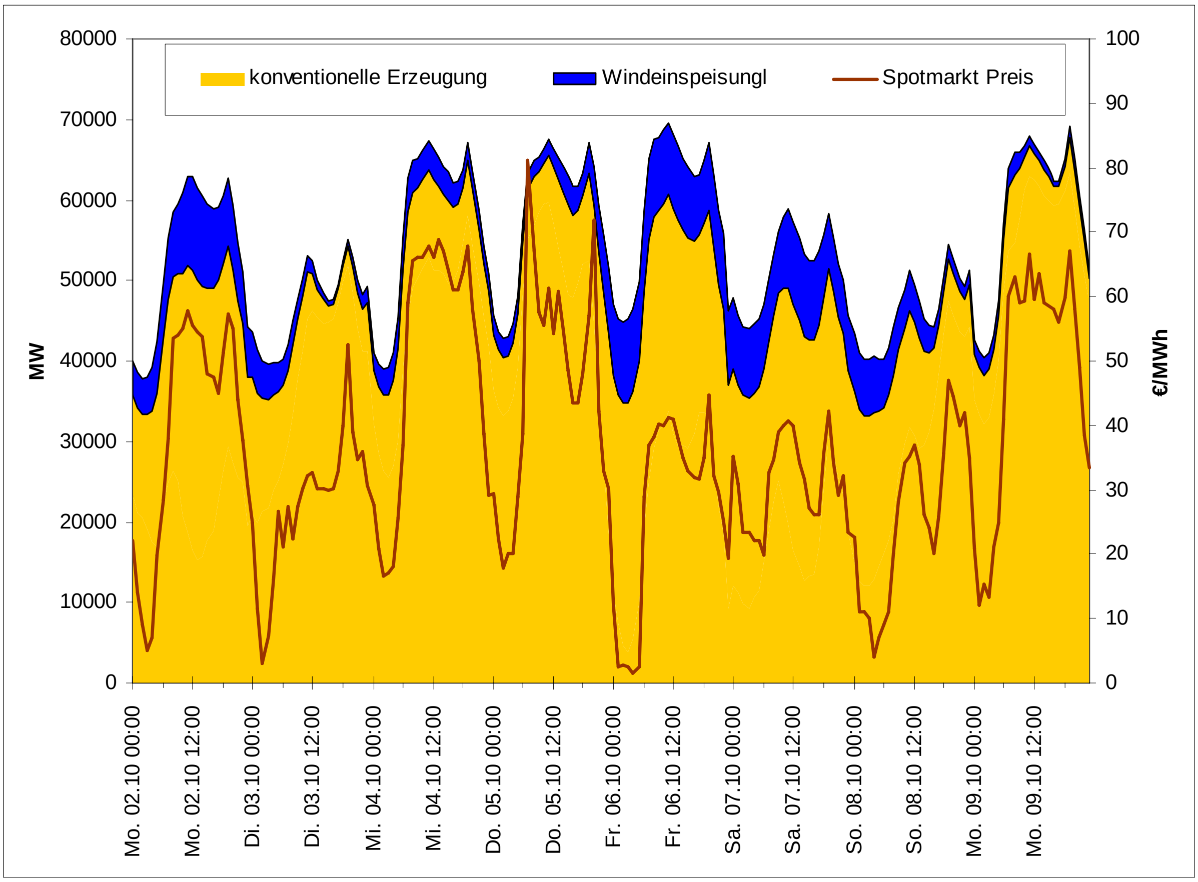


Abb. 1: Beispiel Windeinspeisung und konventionelle Erzeugung sowie Spotmarkt-Preis Anfang Nov. 2006

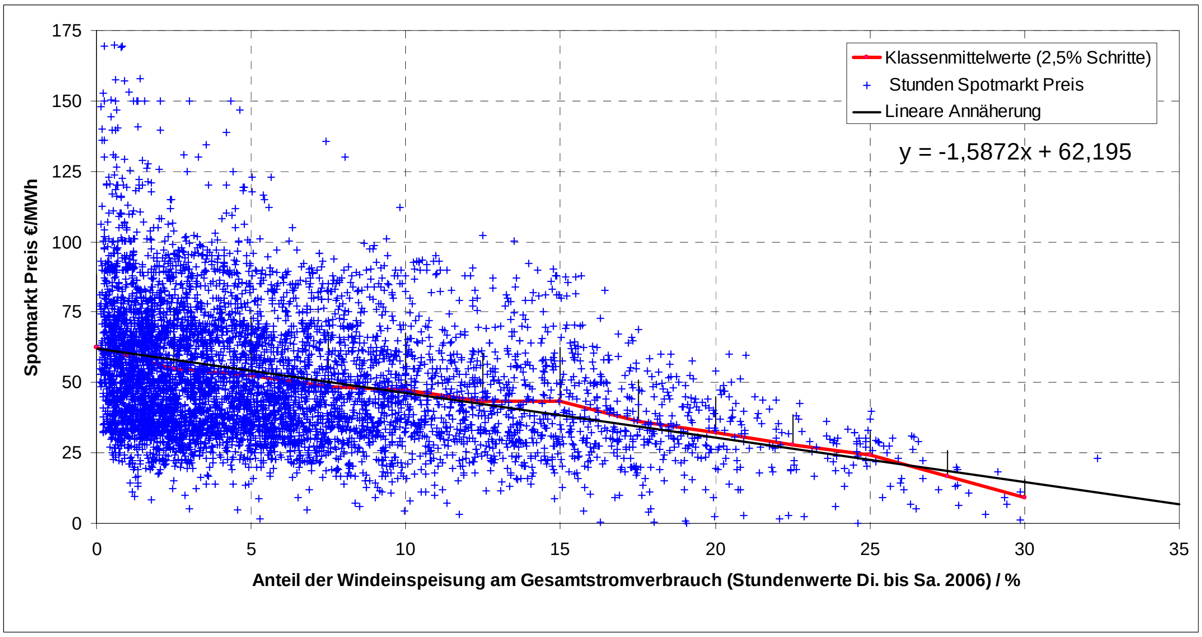


Abb. 2: Spotmarkt Preis in Abhängigkeit des Anteils Windenergieeinspeisung zum Stromverbrauch in 2006 für alle Tage an denen ein Tag im Voraus ein Handel stattgefunden hat (Di.- Sa.).

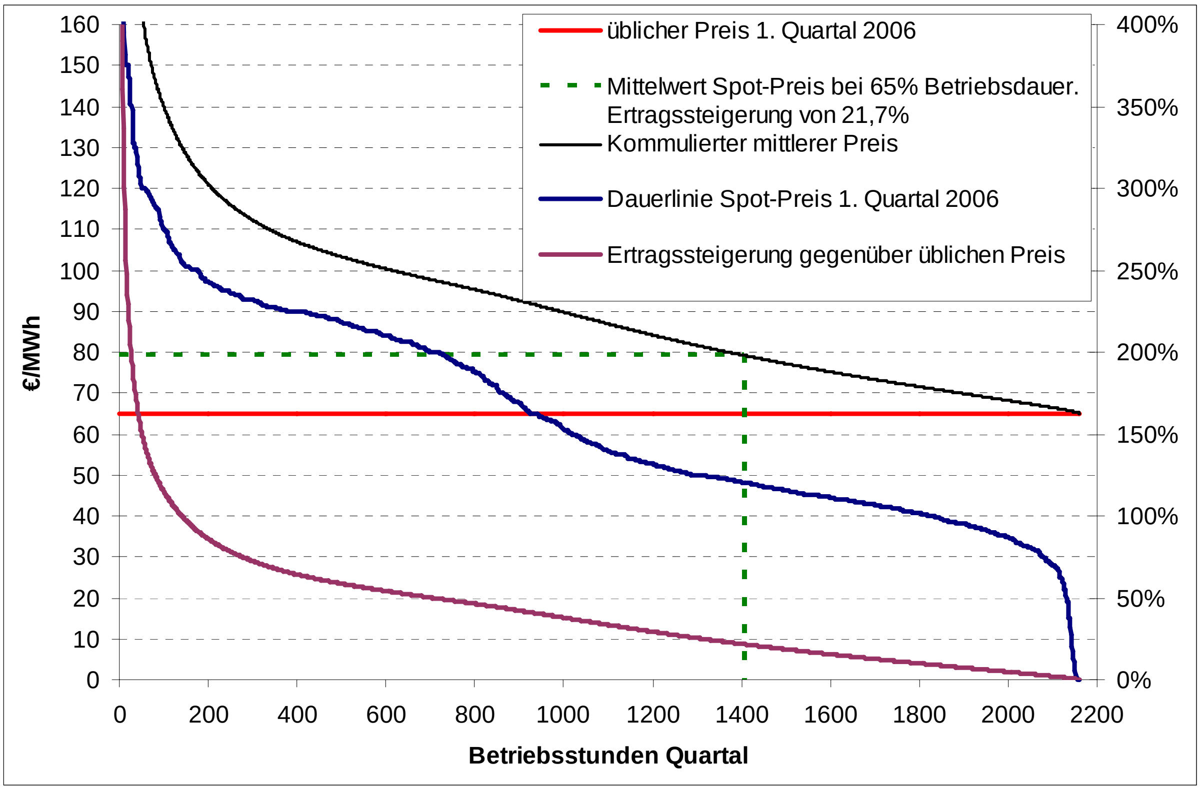


Abb. 3: Ertragssteigerung bei optimaler Vermarktung des KWK-Stroms an der Strombörse

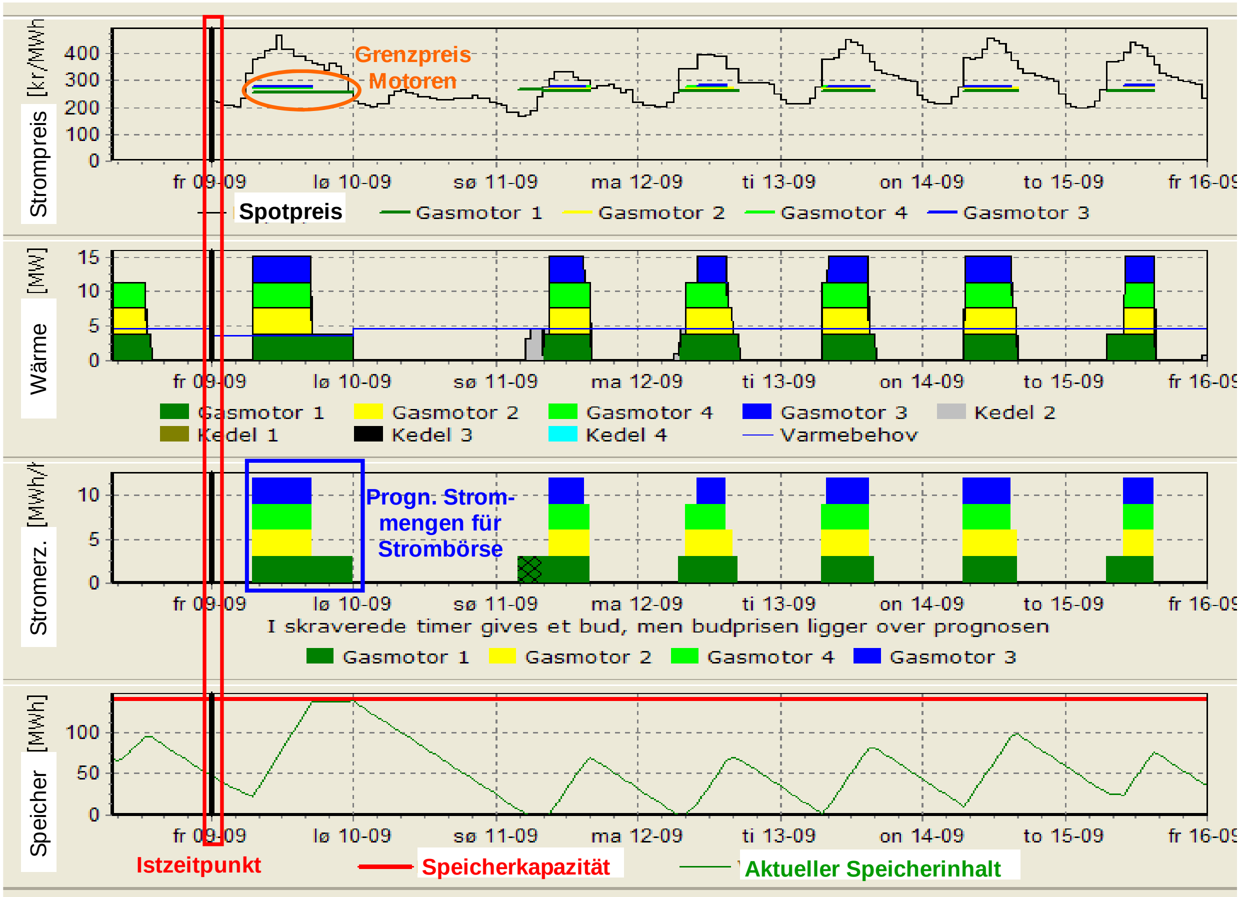


Abb. 4. Bestimmung der Energiemengen für die Angebotsabgabe an der Strombörse für den Folgetag bei optimalem Betrieb und Speicherausnutzung der Anlage mit Hilfe einer 7 Tage Betriebsprognose.

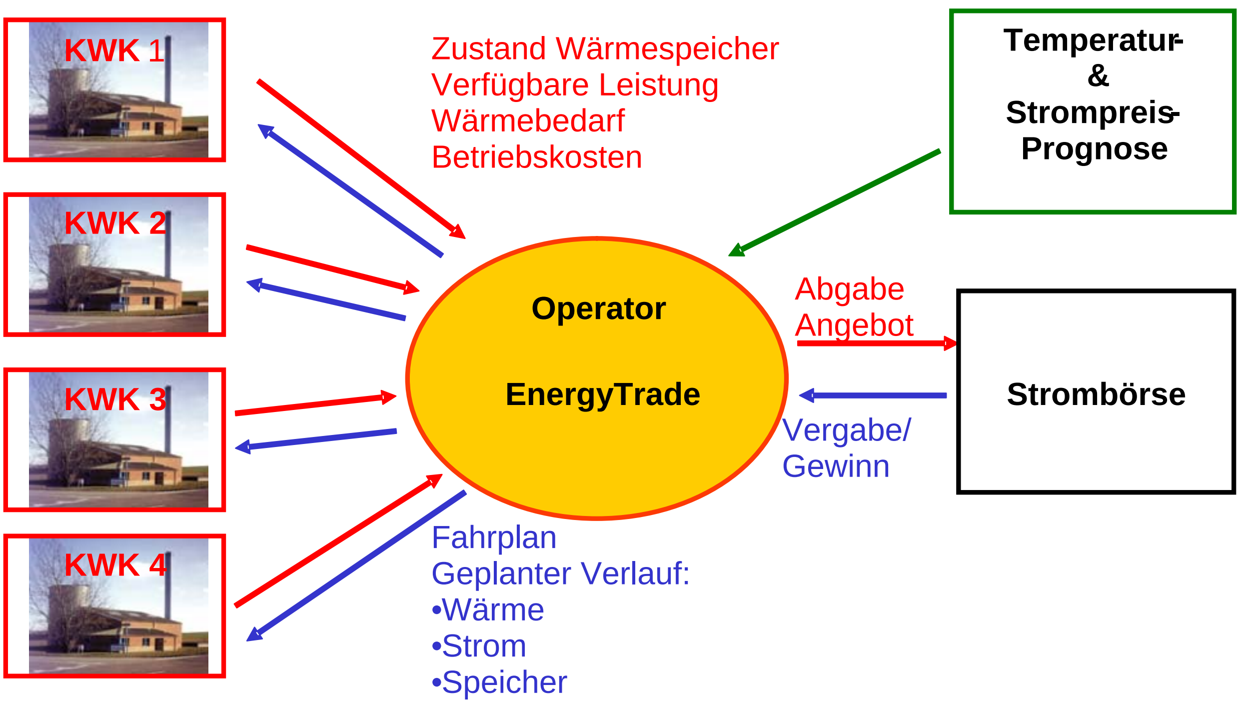


Abb. 5 Pooling und Betrieb von KWK-Anlagen mit großem Wärmespeicher

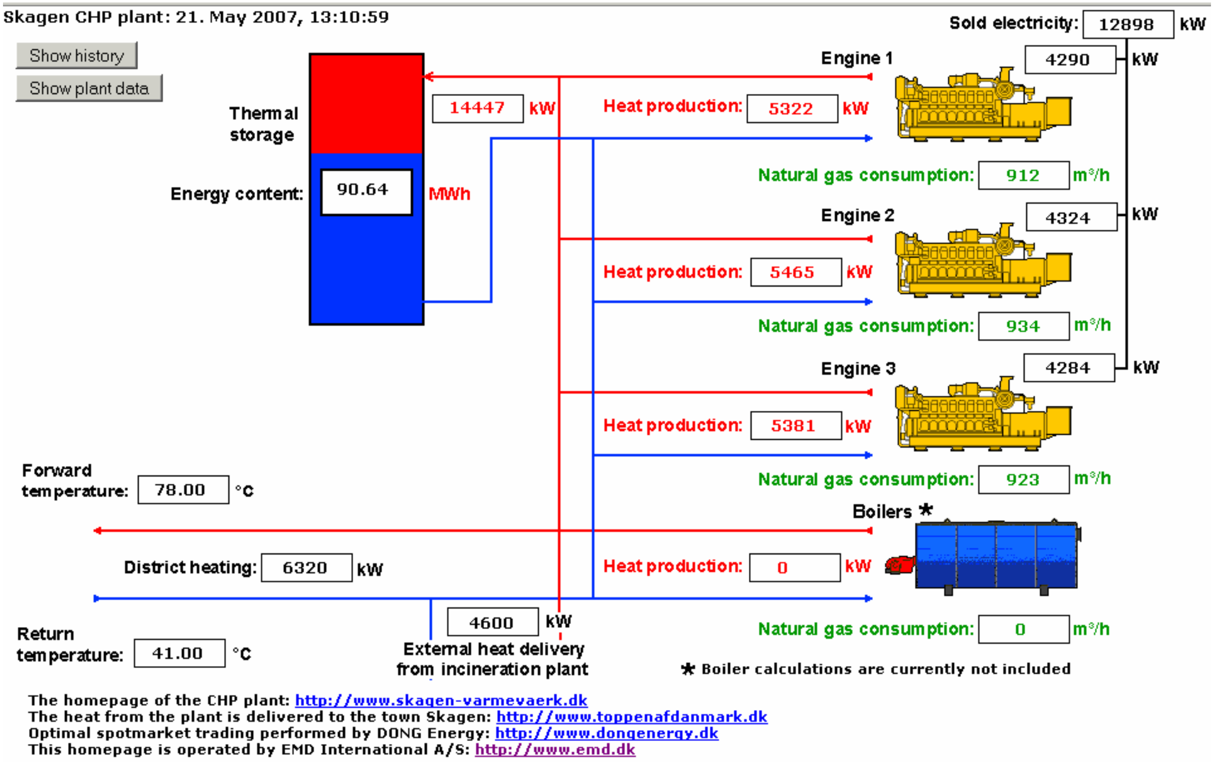


Abb. 6 Online Darstellung KWK-Anlage Skagen DK

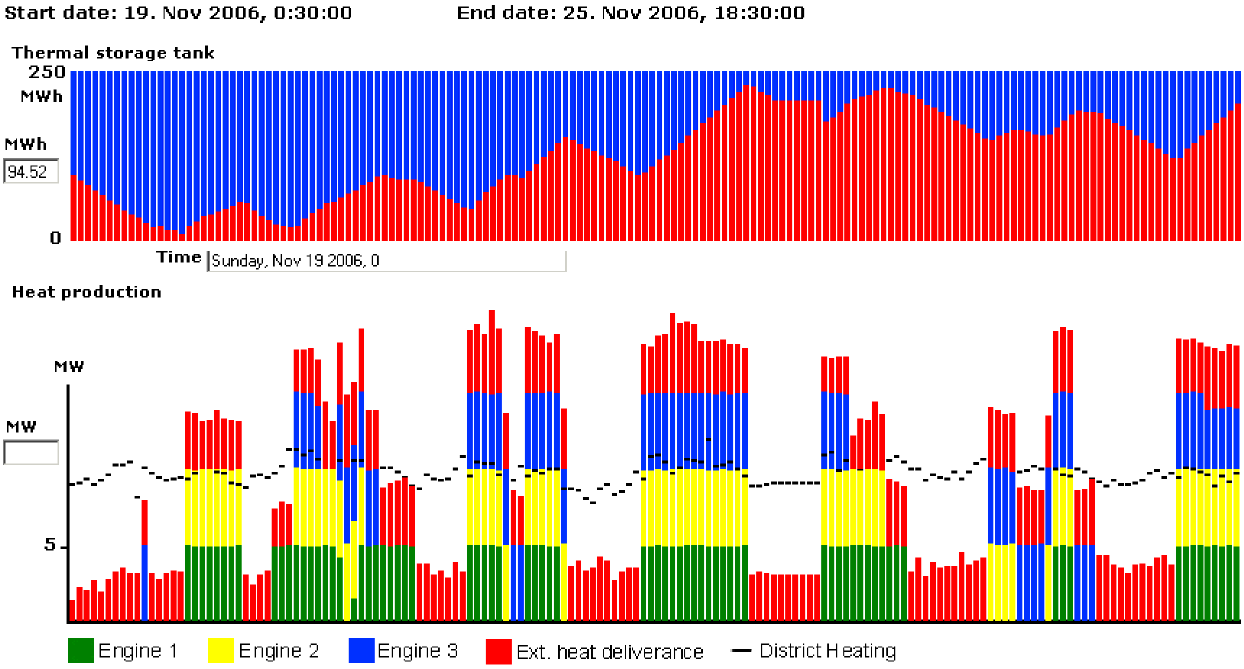


Abb. 7 Online Darstellung KWK-Anlage Skagen DK, Grafiken Speicher und einzelne BHKW über 7 Tage

Zusätzliche Einnahme bzw. Vergünstigung	Kosten	Bemerkungen:
KWK-Bonus /€/MWh$_e$	-12,3€/MWh$_e$	0-22,5€/MWh$_e$ je nach Alter und Größe, Bsp. < 2MWe und älter 2002
Gaskosten für 1MWh$_e$ (entspricht 2,86 MWh Gas, Gaspreis 28€/MWh)	80,0 €/MWh	2006 (ohne Gassteuer wenn <70% Nutzungsgrad
Stromsteuererstattung dezentrale Versorgung	- 12,3 €/MWh$_e$	f. Großverbraucher

Vermiedene Netznutzung	- 3,0 €/MWh_e	20kV Mittelspannungsebene
Zusätzl. Betriebs und Wartungskosten	7,0 €/MWh_e	
Kosten für Handel an der Strombörse	0,5 €/MWh_e	z.B. Südwestdeutsche Stromhandelsgesellschaft
Überschüssige CO2-Zertifikate	0	Erst ab 20 MW Feuerungsleistung
Wärmeerzeugungskosten für 1,34MWh_{th} und 1 MWh_e ohne Erlös durch Vermarktung:	59,9 €/MWh_e	

Wärmeerzeugungskosten mit Kessel (86% Wirkungsgrad) für 1,34 MWh_{th}	**Preis im Vergleich zu 1 MW_e**	
Gassteuer 5,5 €/MWh für Kessel	8,6 €	
Betriebskosten 0,5€/MWh_{th}	0,78 €	
Wärme Erzeugungskosten Gaskessel (Gaspreis 28€/MWh)	43,6 €	Entspricht der Wärmemenge bei Erzeugung 1MWh elektrisch mit der KWK
Summe Erzeugungskosten Kessel für 1,34 MWh_{th}	53,0€	

Grenzpreis mit KWK-Bonus 2006	**6,9€/€/MWh_e**
Grenzpreis ohne KWK-Bonus	**19,2€/€/MWh_e**

Tabelle 1. Bsp. Ermittlung Grenzkosten einer KWK Anlage mit 35% elektrischen und 42% thermischen Wirkungsgrad für die Erzeugung von 1MWh elektrisch.

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Carlos Madina
E-mail	cmedina@labain.es
Title of dissemination	Virtual wind and cogeneration power plant (In Spanish: Central virtual de energía eólica y cogeneración)
Type of activity	Article in peer-reviewed journal
Title of forum	DYNA
Language	Spanish
Date of dissemination	May 7 2007
Place of dissemination	Spain
Brief abstract / description of dissemination activity	The increase of electricity production from renewable energy sources resulted, under certain circumstances, in some operational problems in different countries for the system operator, due to the lack of dispatch capacity of these technologies. Usually, installed capacity and/or electricity output from these plants is limited, but there is an alternative solution, which consists in the joint use of renewable and non-renewable energy sources. This paper presents the results from DESIRE project (contract TREN/05/FP6EN/S07.43516/ 513473), which is funded by the European Commission under the 6th Framework Programme, and which analyses the joint use of wind power and Combined Heat and Power (CHP) to create a Virtual Power Plant, whose output can be dispatched. The analysis carried out in the project demonstrates that these virtual power plants offer benefits to the system as a whole. Nevertheless, present regulatory conditions in the different countries analysed offer barriers to the creation of these virtual power plants. The main barrier for Spain is the lack of flexible CHP, but, under certain circumstances, flexible CHP proves to be more economically feasible than traditional CHP, so it should be considered when installing a new CHP plant.
Audience impact assessment	Although the article has been prepared as a dissemination activity of the project, it will not be published until the project has ended, so impact cannot be assessed.
Dissemination	Included after this form

Central virtual de energía eólica y cogeneración

Carlos Madina (Ingeniero Industrial), Ángel Díaz (Ingeniero Industrial), Pedro Urteaga (Ingeniero de Telecomunicación)
Unidad de Energía**, Labein-Tecnalia**, C/ Geldo - Parque Tecnológico de Bizkaia, Edif. 700
48160 - Derio (Bizkaia)
www.labein.es
Tfno.: 94 607 33 00
Fax: 94 607 33 49

Resumen

El incremento de la producción eléctrica a partir de fuentes de energía renovables ha propiciado que, en determinadas circunstancias, el carácter no gestionable de alguna de ellas haya causado problemas en varios países al operador del sistema. La solución habitual consiste en limitar la instalación y/o la producción eléctrica de este tipo de tecnologías, pero existe otra alternativa, basada en el uso conjunto de estas fuentes renovables y otras no renovables. En concreto, este artículo presenta los resultados del proyecto DESIRE (contrato TREN/05/FP6EN/S07.43516/513473), financiado por la Comisión Europea dentro del 6º Programa Marco, y que consiste en el análisis del uso conjunto de la energía eólica y la cogeneración para formar una "central virtual" (*"Virtual Power Plant"*), cuya producción sea gestionable.

Palabras clave: Generación distribuida, Energía eólica, Cogeneración, Mercado eléctrico, *Virtual Power Plant*

Wind-CHP Virtual Power Plant

Abstract

The increase of electricity production from renewable energy sources resulted, under certain circumstances, in some operational problems in different countries for the system operator, due to the lack of dispatch capacity of these technologies. Usually, installed capacity and/or electricity output from these plants is limited, but there is an alternative solution, which consists in the joint use of renewable and non-renewable energy sources. This paper presents the results from DESIRE project (contract TREN/05/FP6EN/S07.43516/ 513473), which is funded by the European Commission under the 6th Framework Programme, and which analyses the joint use of wind power and Combined Heat and Power (CHP) to create a "Virtual Power Plant", whose output can be dispatched.

Keywords: Distributed generation, Wind power, Combined Heat and Power, Electricity market, Virtual Power Plant

1. Introducción

Uno de los mayores retos a los que se enfrentan las economías europeas es el abastecimiento energético a medio y largo plazo. Actualmente, la dependencia energética de Europa es cercana al 55%, alcanzando el 85% en España. Esta dependencia energética, unida a la inestabilidad de los precios de los combustibles fósiles, hace necesario un cambio en el modelo energético a medio plazo.

Por otra parte, la Unión Europea tiene una serie de compromisos internacionales en materia de protección al medio ambiente, entre los que destaca el cumplimiento del Protocolo de Kioto. De acuerdo con el mismo, los quince socios que componían la Unión Europea antes de la ampliación a 25 Estados Miembros deben reducir hasta 2012 las emisiones de gases de efecto invernadero un 8% con respecto a los niveles registrados en 1990.

La unión de ambos factores ha propiciado la promoción de las fuentes de energía renovables como alternativa a los combustibles fósiles, ya que reducen la dependencia energética exterior y no contribuyen al cambio climático. En este sentido, cabe destacar el gran desarrollo tecnológico que ha experimentado la energía eólica en los últimos años, que le ha permitido convertirse en una fuente de energía importante en determinados Estados Miembros de la Unión Europea, principalmente, en Alemania, España y Dinamarca.

2. Problemática de la energía eólica

A pesar de sus grandes ventajas económicas y medioambientales, la producción de electricidad mediante la fuerza del viento presenta el inconveniente de los errores en la predicción de viento. Si bien se han realizado grandes esfuerzos en la mejora de las herramientas de predicción, los parques eólicos siguen presentando diferencias entre la producción prevista y la producción real.

Mientras la aportación de la energía eólica a la generación de electricidad ha sido testimonial, los errores de predicción de viento se podían asimilar a errores de predicción de la demanda eléctrica y, por lo tanto, se compensaban más o menos fácilmente con las centrales térmicas o hidráulicas. Sin embargo, hoy en día la energía eólica satisface cerca del 8% de la demanda eléctrica en España, habiendo alcanzado máximos horarios de más del 30%. En Dinamarca, la participación ronda el 20%, llegando incluso a superar el 100% de la demanda en determinados momentos.

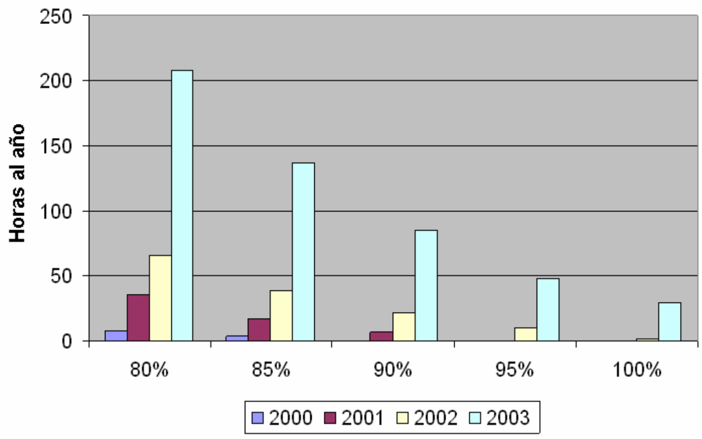


Figura 1. Número de horas anuales en las que la producción eólica supera un porcentaje de demanda en Dinamarca

La solución clásica en estos casos consiste en exportar el exceso de energía a los países vecinos. Sin embargo, en el caso de Dinamarca, el país vecino al que exportar sus excedentes de producción es Alemania, que también tiene instalada gran cantidad de parques eólicos cerca de la frontera danesa. Por lo tanto, en los momentos en los que la producción es alta en Dinamarca, también lo suele ser en Alemania, de manera que la capacidad de absorción de electricidad por parte de Alemania queda limitada. Como consecuencia, es necesario aumentar la capacidad de transporte para evacuar toda la producción eléctrica a partir de energía eólica, o limitar la producción de los parques eólicos, con la consiguiente pérdida de los beneficios que aporta la energía eólica.

Conviene señalar que, debido a la variabilidad del recurso eólico, la producción media anual de un parque eólico se corresponde con la tercera parte de la potencia instalada, es decir, produce sólo una tercera parte de la energía que produciría si generase a potencia nominal durante todo el año. De acuerdo con los datos facilitados por los principales fabricantes de aerogeneradores, las turbinas eólicas empiezan a producir electricidad en el entorno de los 3-4 m/s de viento y alcanzan su potencia nominal cerca de los 15 m/s, dejando de generar por motivos de seguridad mecánica entre los 20 y 25 m/s. Por lo tanto, para que los aerogeneradores produjeran a potencia nominal todo el año, la velocidad de viento debería ser cercana a 15 m/s durante las 8.760 horas del año, lo cual, evidentemente, no ocurre.

A la hora de conceder el permiso para conectar una nueva instalación de producción de electricidad a partir de energía eólica, los operadores del sistema suelen emplear criterios conservadores, considerando como situación más desfavorable aquélla en la que el parque está generando electricidad a potencia nominal en momentos de muy baja demanda. Estos criterios están totalmente justificados por motivos de seguridad y fiabilidad de la red de transporte, pero limitan las posibilidades de participación de la energía eólica en la cobertura de la demanda eléctrica.

Sin embargo, ciertos operadores del sistema han permitido que se instale más potencia que la que cumpliría estrictamente con los criterios de seguridad, a fin de realizar un mejor aprovechamiento de la capacidad de los activos de transporte, siempre y cuando los propietarios de los parques eólicos permitan que el operador del sistema limite su capacidad de producción cuando la seguridad del sistema esté en riesgo. Para garantizar el cumplimiento de dichas limitaciones de producción, en España, se obliga a que todas las instalaciones de producción de energía eléctrica que emplean la fuerza del viento y cuya potencia nominal sea superior a 10 MW estén asociadas a un centro de control, que será quien reciba y ejecute la orden de reducción de producción dada por parte del operador del sistema, actuando sobre los centros de control de los respectivos parques eólicos.

Sin embargo, esta operación, al igual que la solución para evacuar el exceso de producción de Dinamarca, consiste en dejar de aprovechar la energía del viento para producir electricidad, lo cual, en el actual marco de precios caros de combustibles y de preocupación por los efectos del cambio climático, no parece la mejor solución.

3. Solución propuesta

Con el fin de mejorar las soluciones utilizadas hasta la fecha, la Comisión Europea co-financia el proyecto DESIRE[1], dentro del 6º Programa Marco, que consiste en el análisis, demostración y difusión de resultados de una solución conjunta entre la energía eólica y la cogeneración distribuida.

En Dinamarca, la mayor parte de la potencia eólica está instalada en la península, donde también se encuentran la mayoría de las instalaciones de cogeneración de pequeño y mediano tamaño. Tanto una tecnología como la otra se encuentran distribuidas por toda la geografía, de manera que se pueden crear "centrales virtuales" o *"Virtual Power Plants"* en terminología anglosajona, que vendan la producción conjunta de ambas tecnologías. En la Figura 2, aparece la distribución geográfica de la generación eólica y la cogeneración en Dinamarca. Los puntos grises representan los aerogeneradores y los amarillos las plantas de cogeneración distribuidas, mientras que los cuadrados naranjas indican la localización de las centrales térmicas.

Como puede comprobarse en la figura, existe una gran dispersión en cuanto a la instalación, tanto de aerogeneradores, como de plantas de cogeneración pequeñas.

[1] http://www.project-desire.org

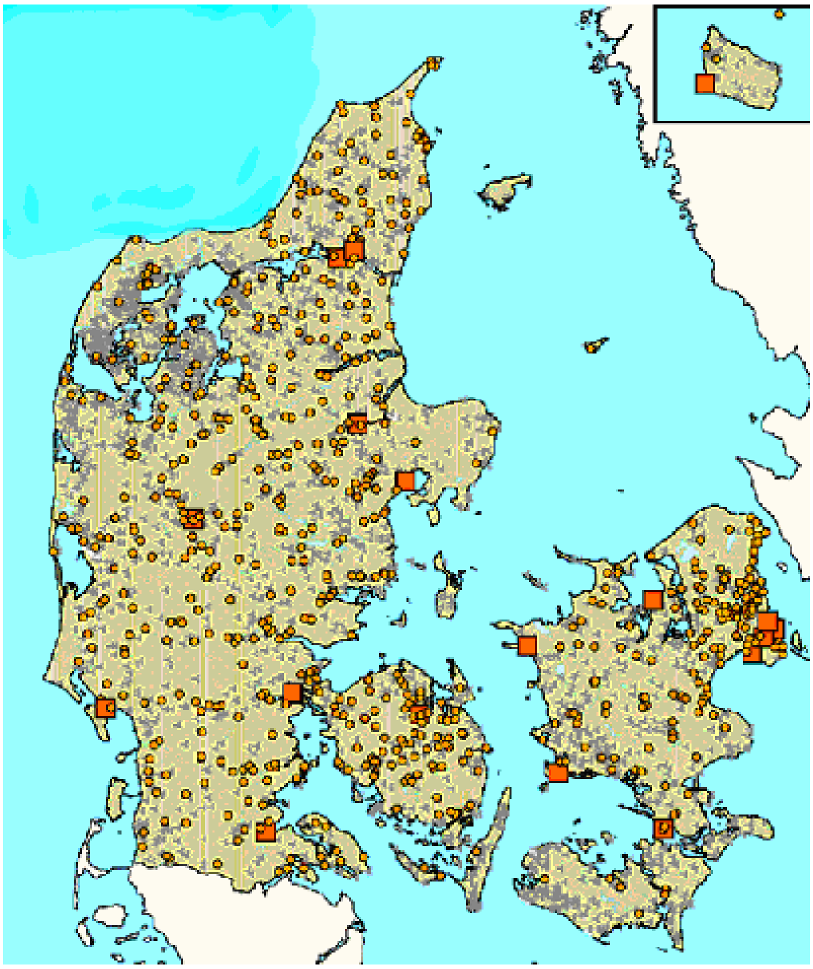


Figura 2. Distribución geográfica de la potencia eólica y de cogeneración en Dinamarca

En estas centrales virtuales, las máquinas eólicas producirán toda la electricidad que puedan, y las plantas de cogeneración modificarán sus perfiles de generación en función de aquéllas. Para ello, las plantas de cogeneración deben ser capaces de modificar su programa de generación, es decir, deben ser flexibles. Muchas de las instalaciones de cogeneración que existen en Dinamarca se emplean para las redes locales de calefacción, de manera que se utilizan para producir agua caliente y no vapor. El agua caliente se puede almacenar en depósitos aislados térmicamente, por lo que no es necesario que la cogeneración siga un patrón determinado, siempre y cuando aporte al depósito de agua una cantidad de energía térmica fija en un determinado periodo de tiempo: día, semana, mes,… Además, la mayoría de las veces, se emplean motores de gas, lo que les permite que los tiempos de arranque y parada sean menores que con otras tecnologías, aumentando a su vez la flexibilidad de la planta.

Así, estas centrales virtuales ya no tienen el problema de falta de predicción que tiene la energía eólica, ya que la cogeneración puede equilibrar los errores de predicción en la generación eólica. Por otra parte, al ser la producción predecible, también pueden ofrecer potencia a subir o a bajar en el mercado de regulación del operador del sistema. Si, además, la instalación se complementa con demanda flexible, como las bombas de calor, aún en los momentos en los que la producción eólica supere la demanda, se pueden poner en marcha las bombas de calor para consumir la electricidad sobrante y producir calor, que se almacenará en los depósitos de agua caliente.

4. Barreras para su aplicación en España

Esta solución, que en Dinamarca parece disponer de todo a su favor, podría emplearse también en otros países, en los que la falta capacidad de despacho de la energía eólica cause problemas en la operación del sistema, como es el caso de España. Para ello, se ha realizado un análisis dentro del proyecto, para comprobar cuáles son las barreras que existen hoy en día y cómo se podrían superar.

4.1. Legislación

Primero, se analizó la legislación vigente a fin de determinar si la solución se podía aplicar desde un punto de vista legal. La legislación europea contiene numerosas directivas que deberían favorecer la implantación de la idea:

- La directiva 96/92/EC estableció las condiciones para la creación de un mercado de electricidad único a escala europea y, posteriormente, la directiva 2003/54/EC subsanó algunas de las lagunas que presentaba el primer documento. Entre las disposiciones de la directiva se establece que el acceso a la red y a los mercados no debe ser discriminatorio y que se debe de promover la competencia. En este sentido, la creación de estas centrales virtuales permite la entrada de nuevos participantes a los mercados eléctricos, lo que incrementará la competencia.
- La directiva 2001/77/EC fue aprobada para fomentar el uso de las fuentes de energía renovables en el mercado interior de electricidad, de manera que un 22.1% de la electricidad consumida en 2010 en la Unión Europea se produjera a partir de energías renovables. Dado que la energía eólica está llamada a ser una de las principales artífices de alcanzar dicho porcentaje, toda acción encaminada a incrementar su participación en la cobertura de la demanda, sin perjudicar el funcionamiento del sistema, estaría en línea con el objetivo de la directiva.
- La directiva 2004/8/EC busca el aumento de la promoción de la cogeneración en el mercado interior de electricidad, siempre y cuando su uso suponga un alto rendimiento energético. Mediante las centrales virtuales, se fomenta el uso de la cogeneración, ya que se convierte en una herramienta útil para los gestores de los parques eólicos, sin necesidad de empeorar el rendimiento térmico, ya que el calor producido se almacena; simplemente se varía el programa de generación.
- Por último, la directiva 2003/87/EC establece el régimen de comercio de derechos de emisión de gases de efecto invernadero, como instrumento para el cumplimiento del Protocolo de Kioto por parte de la Unión Europea. Como se ha mencionado anteriormente, las centrales virtuales de cogeneración y energía eólica permiten aumentar la producción eléctrica a partir de fuentes renovables y fomentan el uso de tecnologías más eficientes, con la consiguiente reducción en la emisión de gases contaminantes.

Todas estas directivas deben transponerse a la legislación de cada uno de los estados miembros. La legislación española tiene varias leyes y reales decretos en los que se fomentan la competencia, el uso de las fuentes de energía renovables, la cogeneración y la protección del medio ambiente: Ley 54/1997 del sector eléctrico y su desarrollo normativo, en el que destacan los reales decretos 2818/1998 y 436/2004 del régimen especial, y la Ley 1/2005 sobre el comercio de emisiones y su desarrollo normativo.

Por lo tanto, la legislación comunitaria en vigor, así como la española, no debería presentar una barrera para las centrales virtuales de cogeneración y energía eólica.

4.2. Mercado

Posteriormente, se analizaron las reglas y las condiciones del mercado eléctrico, para comprobar la capacidad de estas centrales virtuales de acceder al mismo.

En cuanto a las reglas de mercado, se establece que la potencia mínima para entrar en el mercado es de 1 MW, salvo en el caso de plantas de régimen especial, que pueden ser agrupadas por un agente vendedor, a fin de alcanzar la potencia mínima exigida. El hecho de que sea necesaria la agrupación de las plantas de cogeneración y los parques eólicos de menos de 1 MW para acceder al mercado, favorece el uso de las centrales virtuales. Además, no es necesario que las instalaciones agrupadas utilicen la misma tecnología de generación, por lo que el uso de la cogeneración y la energía eólica en un mismo grupo es perfectamente factible.

Sin embargo, la situación actual del mercado eléctrico, en el que dos empresas producen y venden en torno al 60% de la electricidad negociada en el mercado, dificulta la entrada de nuevos participantes. El Real Decreto de tarifas para 2007 establece la obligación de que los operadores dominantes del mercado realicen emisiones primarias de energía, a fin de reducir el control de los mismos sobre el mercado. Estas emisiones primarias consisten en que, si bien los propietarios de las centrales siguen siendo los mismos, son otros quienes comercializan la electricidad afectada por dichas emisiones.

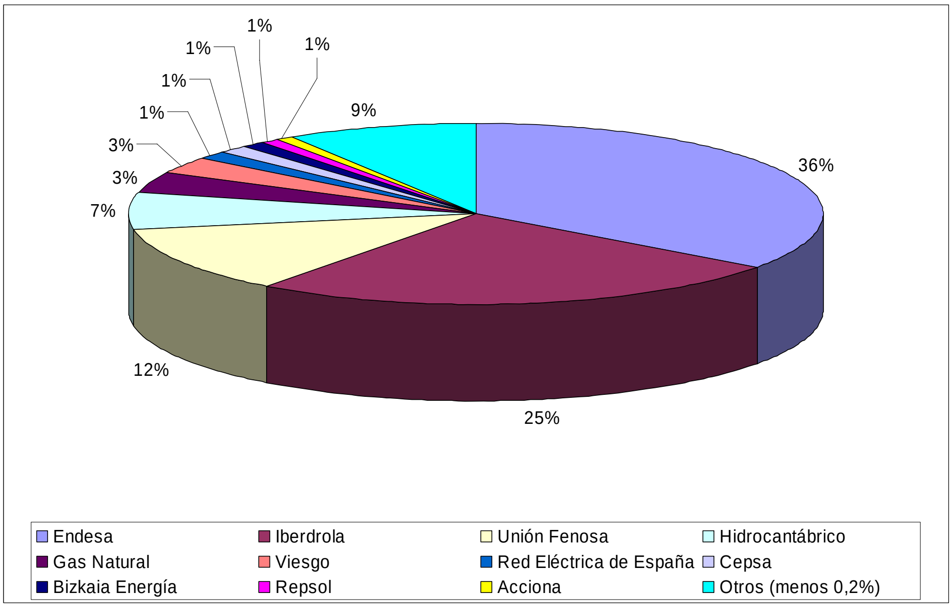


Figura 3. Reparto de participación de las empresas en OMEL en 2005

4.3. Otros

En España, el principal problema para el uso de las centrales virtuales formadas por cogeneración y energía eólica es la falta de cogeneración flexible. La mayor parte de la potencia de cogeneración instalada en España corresponde al sector industrial, donde la producción conjunta de electricidad y calor viene fijada por la demanda térmica del proceso. Además, el calor producido se usa principalmente en forma de vapor, por lo que no se puede almacenar como agua caliente. De esta manera, la demanda de calor no es flexible, ya que está ligada a un proceso industrial, y la producción tampoco se puede diferir respecto a la demanda, porque no es posible almacenar el calor en forma de vapor.

Tanto la legislación comunitaria como la española quieren mejorar la eficiencia energética y señalan que, para ello, la cogeneración deberá desempeñar un importante papel. Si bien el sector industrial sigue presentando potencial de mejora, se estima que el potencial económicamente disponible en los sectores residencial y comercial es aún mayor. En ambos sectores, el calor se emplea principalmente para producir agua caliente, que se puede almacenar fácilmente en un tanque. Por lo tanto, a la hora de diseñar una instalación de cogeneración para el sector residencial o comercial, conviene tener en cuenta la posibilidad de instalar un depósito de agua caliente, que permita modificar el programa de generación de la instalación de cogeneración, de manera que éste se ajuste a una cierta necesidad eléctrica, en lugar de estar condicionado por una demanda térmica. Así, la instalación de cogeneración sería una instalación flexible, ya que podría producir electricidad en los momentos en los que sea más beneficioso para su propietario, siempre y cuando aporte la cantidad de calor necesaria en un determinado espacio de tiempo.

5. ¿Cogeneración flexible o Cogeneración tradicional?

Como se ha mencionado en el apartado anterior, la principal barrera para el uso conjunto de energía eólica y la cogeneración como centrales virtuales en España consiste en la falta de cogeneración flexible. También se ha indicado que, a la hora de analizar las alternativas de diseño de una nueva planta de cogeneración, conviene considerar la instalación de un depósito de agua caliente para crear una planta de cogeneración flexible.

En este apartado se realiza una comparativa de ambas opciones, desde el punto de vista de la rentabilidad de la inversión. En los dos casos, se asumirán las siguientes consideraciones:

- La planta utiliza motores de gas natural.
- El rendimiento eléctrico de los motores es del 35%, y el térmico del 45%.
- La demanda de electricidad es de 5 GWh y la demanda de calor de 20 GWh. Ambas demandas tienen el mismo perfil y que éste coincide con el de la demanda eléctrica del sistema eléctrico español en su conjunto en 2006.
- Cuando la producción de electricidad excede la demanda de la planta, se vende el excedente en el mercado eléctrico. Cuando la demanda no queda satisfecha por la producción local, se compra el resto en el mercado. Los precios de mercado a considerar para el análisis son los del mercado diario español en 2006.
- La prima a recibir es la indicada en el Real Decreto de Régimen Especial, con la actualización de la Tarifa Media o de Referencia correspondiente.
- Los costes operativos de la cogeneración son de 3,5 cent/kWh, correspondientes a 2,5 cent/kWh de combustible y 1 cent/kWh de operación y mantenimiento. El coste de inversión de la planta es de 800 €/kWe.
- La tasa de inflación es del 4%.

De acuerdo a los valores de referencia para cogeneración de alto rendimiento y a la Directiva para la promoción de la cogeneración, la instalación aquí descrita es una instalación de cogeneración de alto rendimiento. De acuerdo al Real Decreto que regula el Régimen Especial, una instalación de cogeneración de alto rendimiento que utiliza gas natural debe tener un autoconsumo mínimo del 10% y un Rendimiento Eléctrico Equivalente del 59%.

5.1. Cogeneración no flexible

La solución que optimiza los beneficios, cumpliendo los requisitos del Real Decreto que regula el Régimen Especial es aquélla en la que la potencia eléctrica de la unidad de cogeneración es de 8 MW. La cogeneración satisface la demanda térmica en todo momento, y funciona a máxima capacidad cuando el precio de mercado es mayor que 8,8 cent/kWh.

Suponiendo una tasa de descuento del 7%, el valor actual neto (VAN) acumulado al final de la vida útil de la instalación (estimada en 15 años) es de 1,46 millones de Euros, mientras que la tasa interna de retorno (TIR) se sitúa en el 10,41%.

5.2. Cogeneración flexible

Para comparar los resultados, la planta de cogeneración flexible también contará con una potencia de 8 MW. Para un coste de instalación del depósito de agua caliente de 1.000 €/m^3, el tamaño óptimo del tanque es de 1.600 m^3.

La operación de la planta buscará obtener el máximo beneficio, en función de los precios de mercado, el calor disponible en el tanque y las limitaciones legales de cara a autoconsumo y rendimiento eléctrico equivalente.

En estas condiciones, para una tasa de descuento del 7%, el valor actual neto de la planta en el 15º año es de 4 millones de Euros, con una tasa interna de retorno del 14,29%.

Tanto desde el punto de vista de la TIR como desde el punto de vista del VAN, la rentabilidad es notablemente mayor en el segundo caso, por lo que se puede comprobar que, en determinadas condiciones, es más conveniente realizar una inversión inicial algo mayor e instalar un depósito de agua caliente que no hacerlo. En consecuencia, conviene realizar este análisis u otro equivalente, a la hora de diseñar una nueva instalación de cogeneración.

La Figura 4 muestra la evolución anual del VAN acumulado para las dos alternativas de inversión analizadas anteriormente.

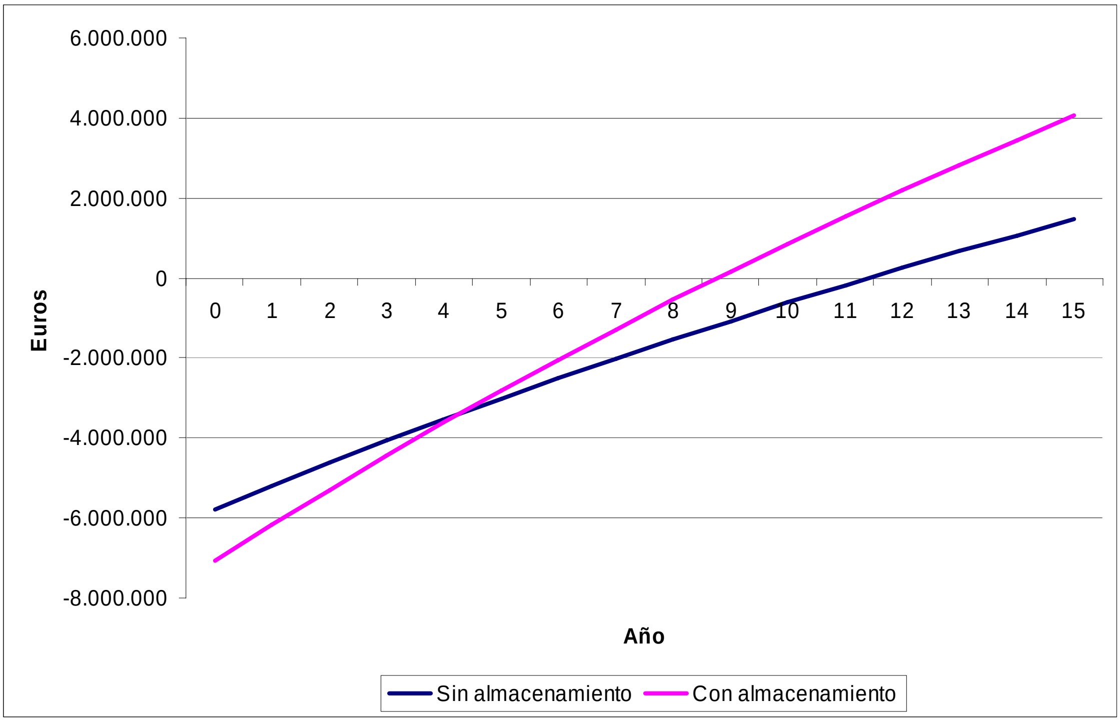


Figura 4. Comparación del VAN acumulado de una planta de cogeneración sin almacenamiento y de una planta de cogeneración con almacenamiento

6. Conclusiones

El uso combinado de la energía eólica y la cogeneración en centrales virtuales aporta ventajas tanto al sistema como al conjunto de la sociedad. Ambas tecnologías reducen las emisiones de gases de efecto invernadero y otros contaminantes, reducen la dependencia energética exterior y permiten la entrada en el mercado de nuevos participantes. Cuando se emplean de manera conjunta, permiten que una tecnología compense las deficiencias de la otra, de manera que los beneficios se multiplican.

El proyecto DESIRE ha analizado las ventajas de estas centrales virtuales y las barreras existentes para su implantación en varios países europeos. Desde un punto de vista teórico, se ha constatado que las centrales virtuales formadas por cogeneración y energía eólica aportan grandes ventajas al sistema eléctrico y a la economía nacional y europea en general. Sin embargo, todos y cada uno de los países analizados presentan alguna barrera que impiden la rentabilidad económica de la inversión en las condiciones actuales.

Por poner un ejemplo, en alguno de los países analizados, las instalaciones eólicas y las cogeneraciones pequeñas no acuden al mercado, ya que pueden vender su electricidad a un precio fijo para cada hora del año, y este precio fijo es muy superior al precio que obtendrían en el mercado. Así, estas cogeneraciones pequeñas no tienen incentivos para modificar su programa de generación, y las instalaciones eólicas no se pueden incluir en centrales virtuales, ya que no acuden al mercado. Para solucionar el problema, se podría incluir un incentivo y una prima para aquellas instalaciones que acudieran al mercado, como se hace en España.

El principal problema detectado en España es la falta de cogeneración flexible: la mayor parte de la cogeneración instalada en España se encuentra en el sector industrial, donde el calor producido se emplea para generar vapor de agua, que no se puede almacenar. Los planes de la Unión Europea para promover la cogeneración pasan por aumentar su participación en el sector comercial y en el sector residencial. En ambos, el calor se emplearía para producir agua caliente, que sí se puede almacenar.

A la hora de diseñar las plantas de cogeneración para estos nuevos sectores objetivo, será importante considerar la posibilidad de que sean plantas de cogeneración flexibles. El análisis realizado en el presente artículo demuestra que, en determinadas condiciones, la viabilidad de la cogeneración flexible puede ser mayor que la de una planta de cogeneración tradicional.

7. Referencias

[1] *“Directiva 96/92/CE del Parlamento Europeo y del Consejo, de 19 de diciembre de 1996, sobre normas comunes para el mercado interior de la electricidad”,* Diario Oficial de las Comunidades Europeas, L 027, pp.020-029, 30 enero 1997

[2] *“Directiva 2001/77/CE del Parlamento Europeo y del Consejo, de 27 de septiembre de 2001, relativa a la promoción la electricidad generada a partir de fuentes de energía renovables en el mercado interior de la electricidad”,* Diario Oficial de las Comunidades Europeas, L 283, pp.033-040, 27 octubre 2001

[3] *“Directiva 2003/54/CE del Parlamento Europeo y del Consejo, de 26 de junio de 2003, sobre normas comunes para el mercado interior de la electricidad y por la que se deroga la Directiva 96/92/CE”,* Diario Oficial de las Comunidades Europeas, L 176, pp.037-055, 15 julio 2003

[4] *“Directiva 2003/87/CE del Parlamento Europeo y del Consejo, de 13 de octubre de 2003, por la que se establece un régimen para el comercio de derechos de emisión de gases de efecto invernadero en la Comunidad y por la que se modifica la Directiva 96/61/CE del Consejo”,* Diario Oficial de las Comunidades Europeas, L 275, pp.032-046, 25 octubre 2003

[5] *“Directiva 2004/8/CE del Parlamento Europeo y del Consejo, de 11 de febrero de 2004, relativa al fomento de la cogeneración sobre la base de la demanda de calor útil en el mercado interior de la energía y por la que se modifica la Directiva 94/42/CEE”,* Diario Oficial de las Comunidades Europeas, L 052, pp.050-060, 21 febrero 2004

[6] *“Decisión de la Comisión, de 21 de diciembre, por la que se establecen valores de referencia de la eficiencia armonizados para la producción por separado de electricidad y calor de conformidad con lo dispuesto en la Directiva 2004/8/CE del Parlamento Europeo y el Consejo”,* Diario Oficial de la Unión Europea, L 32, pp.183-188, 6 febrero 2007

[7] *“Ley 54/1997, de 27 de noviembre, del sector eléctrico”,* Boletín Oficial del Estado (BOE) núm. 285, pp.35097-35126, 28 noviembre 1997

[8] Ministerio de Economía *“Real Decreto 436/2004, de 12 de marzo, por el que se establece la metodología para la actualización y sistematización del régimen económico de la actividad de producción de energía eléctrica en régimen especial”*, Boletín Oficial del Estado (BOE) núm. 75, pp.13217-13238, 27 marzo 2004

[9] Ministerio de Economía *“Orden ITC/3992/2006, de 29 de diciembre, por la que se establecen las tarifas de gas natural y gases manufacturados por canalización, alquiler de contadores y derechos de acometida para los consumidores conectados a redes de presión de suministro igual o inferior a 4 bar”,* Boletín Oficial del Estado (BOE) núm. 312, pp.46684-46692, 30 diciembre 2006

[10] Ministerio de Industria, Turismo y Comercio, *“Real Decreto 1454/2005, de 2 de diciembre, por el que se modifican determinadas disposiciones relativas al sector eléctrico”*, Boletín Oficial del Estado (BOE) núm. 306, pp.41897-41916, 23 diciembre 2005

[11] Ministerio de Industria, Turismo y Comercio, *“Real Decreto 1556/2005, de 28 de diciembre, por el que se establece la tarifa eléctrica para 2006”*, Boletín Oficial del Estado (BOE) núm. 310, pp.42576-42600, 28 diciembre 2005

[12] Ministerio de Industria, Turismo y Comercio, *"Resolución de 24 de mayo de 2006, de la Secretaría General de Energía, por la que se aprueban las Reglas de funcionamiento del mercado diario e intradiario de producción de energía eléctrica"*, Boletín Oficial del Estado (BOE) núm. 128, pp.20155-20192, 30 mayo 2006

[13] Ministerio de Industria, Turismo y Comercio, *"Real Decreto 1634/2006, de 29 de diciembre, por el que se establece la tarifa eléctrica a partir del 1 de enero de 2007"*, Boletín Oficial del Estado (BOE) núm. 312, pp.46656-46679, 30 diciembre 2006

[14] Información on-line sobre el proyecto DESIRE, http://www.project-desire.org

[15] Ecotècnia, Información on-line sobre aerogeneradores, http://www.ecotecnia.com/

[16] Gamesa, Información on-line sobre aerogeneradores, http://www.gamesa.es/gamesa/index.html

[17] GE Wind, Información on-line sobre aerogeneradores, http://www.gepower.com/prod_serv/products/wind_turbines/en/15mw/index.htm

[18] Vestas, Información on-line sobre aerogeneradores, http://www.vestas.com/vestas/global/en/Products/Wind_turbines/

[19] OMEL, Información on-line sobre precios del mercado, http://www.omel.com/frames/es/resultados/resultados_index.htm

[20] REE, Información on-line sobre demanda del sistema peninsular, http://www.ree.es - Operación del Sistema Eléctrico > SIMEL > Perfiles de consumo > Selector de Ficheros

[21] Madina C., Laresgoiti I., Sanz M.A. et al., "D3.2: Potential for access to electricity markets for the demonstration projects in the different country-case studies", DESIRE project (TREN/05/FP6EN/S07.43516/513473), 2005, on-line http://www.project-desire.org

[22] Roqueta, J.Mª; "La cogeneración en el sistema energético y en la política energética de España y Europa", Rueda de Prensa de Cogen España, Madrid, 30 junio 2004, http://www.cogenspain.org/comunicados/COG0406NP.0.pdf

Dissemination strategy on Electricity balancing

DESIRE

large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Krzysztof Wojdyga, Marcin Lec, Rafal Laskowski Warsaw University of technology
E-mail	krzysztof.wojdyga@is.pw.edu.pl
Title of dissemination	Renewable Energy Production – the Comparison for Countries Members of DESIRE Project.
Type of activity	Presentation at conference Article in conference proceedings
Title of forum	I International Conference on Solar Energy and Ecobuildings. RENEWABLE ENERGY - Innovative ideas and technologies for buildings.
Language	Polish
Date of dissemination	May 17 – 20 , 2006
Place of dissemination	Solina Poland
Brief abstract / description of dissemination activity	The situations of energy market in the countries participate in DESIRE project are different. In this paper the situation sources of energy, especially renewable sources of energy are presented. Energy assumptions these countries till 2025 with special including renewable sources of energy are shown.
Audience impact assessment	The presentation at the conference was received with great interest. Discussion was connected to differences in production sources of electricity production in DESIRE – countries and directions of development renewable energy in Poland. The article has been published in conference proceedings prepared by Resovia University of Technology "Folia Scientiarum Universitatis Resoviensis". Conference materials consist of 79 articles connected to renewable energy sources.
Dissemination	Included after this form

ZESZYTY NAUKOWE
POLITECHNIKI RZESZOWSKIEJ

FOLIA SCIENTIARUM
UNIVERSITATIS TECHNICAE RESOVIENSIS

NR 229

BUDOWNICTWO
I INŻYNIERIA ŚRODOWISKA

z. 40

pod redakcją Lecha Lichołai

PIERWSZA MIĘDZYNARODOWA KONFERENCJA ENERGII SŁONECZNEJ
I BUDOWNICTWA EKOLOGICZNEGO

Jubileusz X lecia Polskiego Towarzystwa Energetyki Słonecznej

ENERGIA ODNAWIALNA
Innowacyjne idee i technologie dla budownictwa
17 - 20 maja 2006

THE FIRST INTERNATIONAL CONFERENCE ON SOLAR ENERGY AND ECOBUILDINGS

X Anniversary of the Polish Solar Energy Society

RENEWABLE ENERGY
Innovative ideas and technologies for buildings
May 17 -20, 2006

SOLINA 2006

SOLINA

Pierwsza Międzynarodowa Konferencja Energii Słonecznej
i Budownictwa Ekologicznego
ENERGIA ODNAWIALNA
Innowacyjne idee i technologie dla budownictwa
SOLINA 2006

Krzysztof WOJDYGA, dr inż.
Rafał LASKOWSKI, mgr inż.
Marcin LEC, mgr inż.

Politechnika Warszawska
Wydział Inżynierii Środowiska i Mechaniczny Energetyki i Lotnictwa
ul. Plac Politechniki 1, 00-661 Warszawa
e-mail: krzysztof.wojdyga@is.pw.edu.pl

PRODUKCJA ENERGII ODNAWIALNEJ _ ANALIZA PORÓWNAWCZA DLA 6 KRAJÓW EUROPEJSKICH

STRESZCZENIE

Projekt DESIRE ma za zadanie określenie możliwości współpracy odnawialnych źródeł energii elektrycznej, jakimi są elektrownie wiatrowe ze źródłami skojarzonej produkcji energii elektrycznej i ciepła (CHP) w systemie elektroenergetycznym. Poniższy referat porównuje sytuację na rynku energii odnawialnych w krajach biorących udział w tymże projekcie.

1. WPROWADZENIE

W referacie szczególnym rozważaniom poddano energetykę odnawialną. Przedstawiono również teraźniejszą sytuację energetyczną oraz zamierzenia i strategie rozwoju energetyki w poszczególnych krajach. Pod uwagę wzięto następujące kraje: Polska, Hiszpania, Niemcy, Dania, Wielka Brytania (Szkocja) i Estonia.

2. CHARAKTERYSTYKA ROZWOJU SEKTORA ENERGETYCZNEGO

W celu zapewnienia ciągłości dostaw energii elektrycznej i ciepła większość krajów tworzy narodowe programy rozwoju rynku energii. W programach tych opisuje się sytuację energetyczną krajów, prognozuje się zapotrzebowanie i kierunki rozwoju źródeł wytwarzających energię elektryczną i ciepło. Porównano scenariusze dotyczące produkcji ciepła i energii elektrycznej do roku 2020 w krajach biorących udział w projekcie DESIRE. Szczególną uwagę poświęcono obecnej i przyszłej sytuacji energetyki odnawialnej (wiatrowej) i skojarzonym źródłom energii. Poniżej przedstawiono główne założenia w scenariuszach rozwoju rynków energii dla wybranych krajów biorących udział w projekcie DESIRE. W tabelach 1 i 2 przedstawiono udział poszczególnych rodzajów paliw w produkcji energii elektrycznej i ciepła w wybranych 6 państwach UE.

Tabela 1 Produkcja energii elektrycznej w krajach uczestnikach projektu DESIRE
Table 1 Power generation in DESIRE –project participants states

Państwo	energia elektryczna		udział w produkcji energii %				
	moc GW	produkcja TWh/a	nuklearna	węgiel	olej opałowy	gaz ziemny	odnawialne
Niemcy	116	580	28	49	2	10	9
Dania	13	44	0	55	21	5	19
Hiszpania	72	265	24	29	5	21	21
Estonia	2,5	9,2	0	0	98	2	0
Polska	35	150	0	95	0	2	3
Wielka Brytania	77	400	19	33	1	41	4

Tabela 2 Produkcja ciepła w krajach uczestnikach projektu DESIRE
Table 2 Heat generation in DESIRE –project participants states

Państwo	ciepło TWh/a		udział w produkcji ciepła %				
	ogrzewanie	w skojarzeniu	energia elektryczna	węgiel	olej opałowy	gaz ziemny	odna-wialne
Niemcy	870	105	6	11	32	51	0
Dania	197	106	4	13	18	35	29
Hiszpania	b.d	b.d	38	4	14	41	3
Estonia	44	b.d	0	1	20	52	23
Polska	300	92	0	87	3,5	7	0
Wielka Brytania	556	62	5	2	7	85	0

W Polsce przewiduje się, że produkcja energii elektrycznej wzrośnie z 141,5 TWh w 2002 roku do 290,2 TWh w 2025 roku (średni roczny wzrost około 4,8 %). Istniejące duże skojarzone źródła spalające węgiel będą natomiast modernizowane a część z nich będzie zastąpiona źródłami spalającymi gaz.

W Danii natomiast szacuje się, że zapotrzebowanie na energię elektryczną wzrośnie z 35,3 TWh w 2001 roku do 41,1 TWh w 2020 roku, (średni roczny wzrost około 0,8%). Istniejące duże źródła skojarzone spalające węgiel będą zastępowane po przekroczeniu czasu żywotności jednostkami spalającymi gaz.

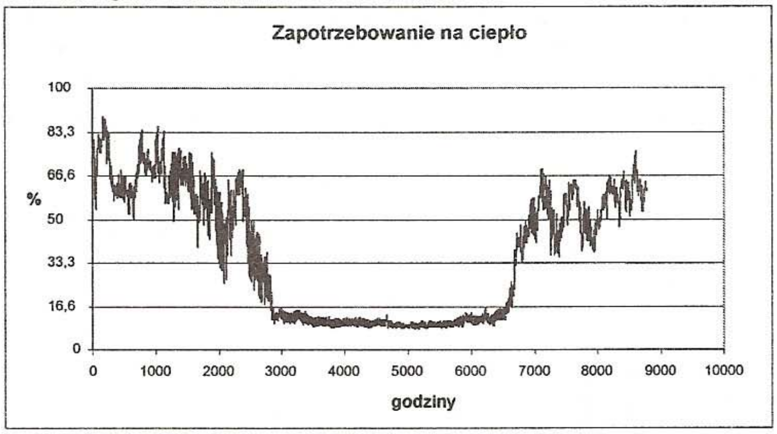
W Hiszpanii przewiduje się, że średni roczny wzrost zapotrzebowanie na energię elektryczną wyniesie około 3 %, co oznacza, że w 2020 roku wzrośnie do poziomu 378 TWh. Zakłada się wzrost moc zainstalowanej w skojarzonych źródłach energii do poziomu 7 100 MW w 2011 roku. W 2020 roku szacuje się, że moc zainstalowana w skojarzonych źródłach wyniesie około 9 000 MW.

W Niemczech natomiast odwrotnie do pozostałych krajów przewiduje się, że zapotrzebowane na energię elektryczną spadnie z 581 TWh w 2004 roku do 495 TWh w 2020 roku. W scenariuszu rozwoju tzw. „ekologicznym" zakłada się, że nastąpi redukcję mocy zainstalowanej w elektrowniach jądrowych i opalanych węglem brunatny a nastąpi wzrost wykorzystania gazu. Zakłada się większy udział skojarzonych jednostek źródeł ciepła i wzrost udziału energii elektrycznej produkowanej z elektrowni wiatrowych.

W Estonii zakłada się, że zapotrzebowanie na energię elektryczną wzrośnie z 5,5 TWh w 2001 roku do 8,0 TWh w 2020 roku.

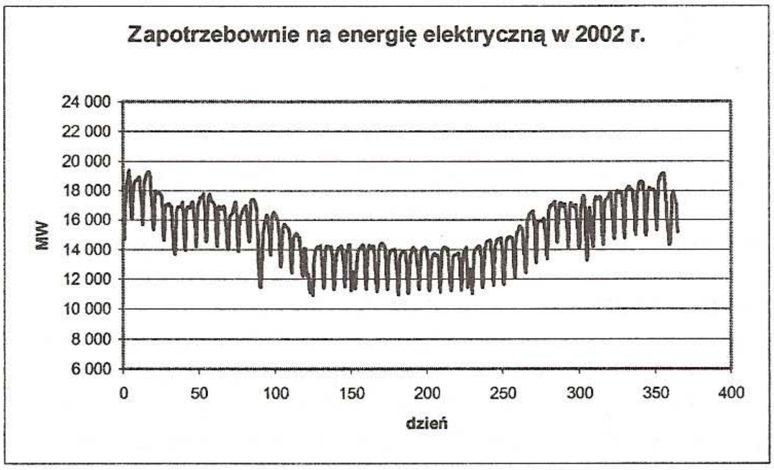
We wszystkich krajach biorących udział w projekcie DESIRE zakłada się wzrost produkcji energii elektrycznej z elektrowni wiatrowych jak również wzrost zainstalowanej mocy w skojarzonych źródłach energii.

Przykładowo na rys.1 pokazano roczne zapotrzebowanie na ciepło dla typowego systemu ciepłowniczego.



Rys.1. Zapotrzebowanie na ciepło dla typowego systemu ciepłowniczego
Fig.1. Heating demand

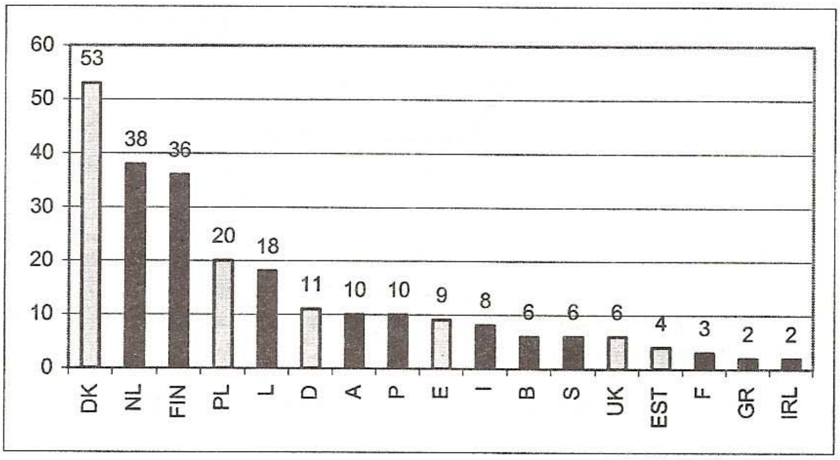
Roczne zapotrzebowanie na energię elektryczną w Polsce w roku 2002 (źródło PSE 2003) przedstawiono na rys. 2.



Rys.2. Zapotrzebowanie na moc elektryczną
Fig.2. Electricity demand

Na podstawie rysunku 2 można stwierdzić, że występuje pewna analogia między zapotrzebowaniem ciepła i energii elektrycznej. W miesiącach zimowych zapotrzebowanie na energię elektryczną wzrasta a w miesiącach letnich zmniejsza się, podobnie jak dla zapotrzebowania na ciepło. Podobny charakter zmian zapotrzebowania na energię elektryczną występuje w pozostałych krajach biorących udział w projekcie DESIRE za wyjątkiem Hiszpanii, w której zapotrzebowanie na energię elektryczną w ciągu roku jest praktycznie stałe.

Najbardziej racjonalnym wytwarzaniem energii elektrycznej i ciepła są nowoczesne układy skojarzonego wytwarzania obu rodzajów energii (układy kogeneracyjne) w których uzyskuję się ponad. 30 % ograniczenie zużycia paliw pierwotnych, w stosunku do produkcji rozdzielonej. produkcja energii w układach skojarzonych powinna być preferowana. Oprócz istniejących źródeł powstawać będą nowe inwestycje zgodne z Dyrektywą 2004/8/WE w sprawie promowania kogeneracji w oparciu o zapotrzebowanie na ciepło użytkowe na wewnętrznym rynku energii. Na rysunku 3 przedstawiono udział produkcji energii elektrycznej w skojarzeniu w krajach Unii Europejskiej.



Rys.3 Udział energii elektrycznej wyprodukowanej w skojarzeniu do calkowitej produkcji w krajach UE.
Fig.3 Fraction of co-generated electricity on total electricity generation for EU

3. ENERGETYKA WIATROWA I SŁONECZNA

W tabeli 3 przedstawiono produkcję energii elektrycznej ze źródeł odnawialnych dla Polski. Przewiduje się, że moc zainstalowana w elektrowniach wiatrowych wzrośnie z 63 MW w 2003 roku do 2 000 MW w 2025 roku. To założenie jest jednak mało prawdopodobne, ponieważ żaden rządowy dokument nie zawiera informacji odnośnie rozwoju elektrowni wiatrowych.

Tabela 3. Odnawiane źródła energii
Table 3. Renewable sources

	2003			2020	
	Ilość jednostek	Moc MW	Produkcja elektryczna GWh	Moc MW	Produkcja elektryczna GWh
Małe elektrownie	516	59	181	300	800
Biogaz	49	20	56	100	300
Wiatrowe elektrownie	31	60	124	1000	2000

Szacuje się, że w Polsce moc pozyskana z energii słonecznej wynosi od 100 do 150 kW.

W tabeli 4 przedstawiono produkcję energii elektrycznej z odnawialnych źródeł energii w Danii. Zakłada się, że zainstalowana moc w elektrowniach wiatrowych wzrośnie z 570 MW w 2001 roku do 1 850 MW dla wschodniej części Danii z 1 870 MW do 3 860 MW w zachodniej części Danii w 2020 roku.

Tabela 4. Odnawiane źródła energii
Table 4. Renewable sources

	2004	**2020**
Lądowe elektrownie wiatrowe	2 185 MW / 5,44 TWh	2 500 MW / 6,05 TWh
Elektrownie wiatrowe na morzu	160 MW / 0,71 TWh	1 445 MW / 6,11 TWh
Energia słoneczna	0,6 MW / 0,6 GWh	0,6 MW / 0,6 GWh

W tabeli 5 przedstawiono produkcję energii elektrycznej ze źródeł odnawialnych dla Hiszpanii. Zakłada się, że zainstalowana moc w elektrowniach wiatrowych w 2010 będzie wynosiła 20155MW. Zakłada się średnio roczny wzrost na poziomie 1 500 MW/rok w latach 2010 do 2020. Moc elektryczna zainstalowana w elektrowniach wiatrowych w 2020 roku powinna wynosić około 40 000 MW.

Tabela 5. Odnawiane źródła energii
Table 5. Renewable sources

	2004	**2020**
Lądowe elektrownie wiatrowe	8 351 MW / 15,6 TWh	35 000 MW / 70 TWh
Elektrownie wiatrowe na morzu	0 MW / 0,0 TWh	5 000 MW / 15 TWh
Energia słoneczna	16 MW/ 0,017 TWh	2 400 MW / 4,8 TWh

W tabeli 6 przedstawiono produkcję energii elektrycznej z odnawialnych dla Niemiec. Zakłada się, że moc zainstalowana w elektrowniach wiatrowych wzrośnie z 16 600 MW do 48 000 MW w 2020 roku.

Tabela 6. Odnawialne źródła energii
Table 6. Renewable sources

	2004	**2020**
Lądowe elektrownie wiatrowe	16 629 MW / 25 TWh	28 000 MW / 76 TWh
Elektrownie wiatrowe na morzu	0 MW / 0 TWh	20 000 MW / 54,9 TWh
Energia słoneczna	705 MW / 0,5 TWh	5 400 MW / 5,2 TWh

Elektrownie wiatrowe w Niemczech są zlokalizowane głównie na północy kraju. Na południu kraju moc zainstalowana w elektrowniach wiatrowych jest bardzo mała. Natomiast ludność głównie jest zlokalizowana na południu i zachodzie kraju. Na północy gdzie jest najwięcej zainstalowanej mocy w elektrowniach wiatrowych jest małe zaludnienie, dlatego energia elektryczna z elektrowni wiatrowych musi być transportowana z wybrzeża na południe i zachód. Na podstawie planu rozwoju energetyki ze źródeł odnawialnych zakłada się, że do 2020 roku w Niemczech moc zainstalowana w elektrowniach wiatrowych osiągnie poziom 48.300 MW. Taka ilość mocy zainstalowanej nie może być bilansowana tylko lokalnie czy regionalnie, wyraźnie widać, że musi byc bilansowana na obszarze całego kraju.

Moc zainstalowana w ogniwach fotovoltaicznych wzrasta bardzo szybko, ale w porównaniu do mocy z elektrowni wiatrowych czy elektrowni wodnych jest na niskim poziomie. Energetyka słoneczna ma najmniejszą moc zainstalowaną ze wszystkich źródeł odnawialnych.

W tabeli 7 przedstawiono produkcję energii elektrycznej z odnawialnych źródeł energii dla Szkocji.

Tabela 7. Odnawiane źródła energii
Table 7. Renewable sources

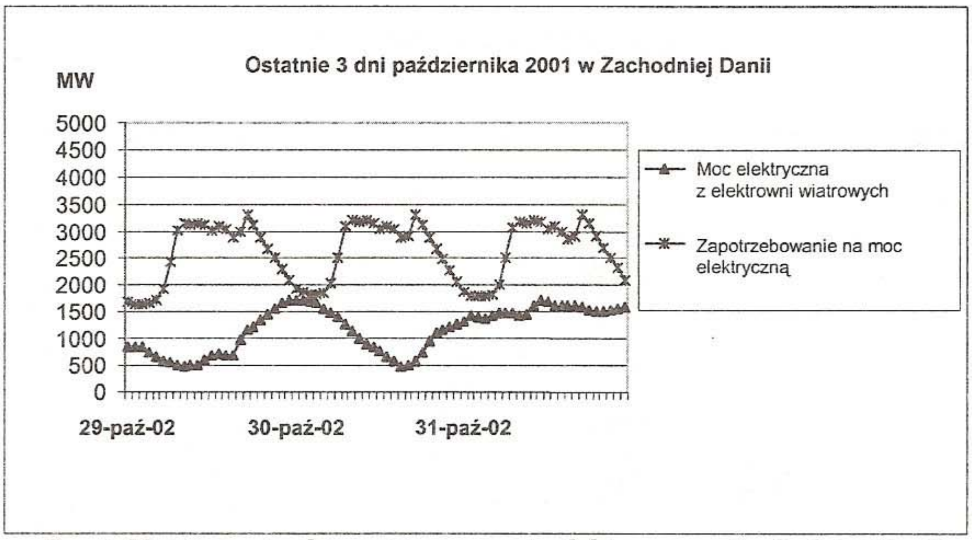
	2004	2020
Elektrownie wiatrowe	172,1 MW / 0,469 TWh	3 000 MW / 8,031 TWh
Energia słoneczna	611,0 kW / 298,0 MWh	30,5 MW / 15,0 GWh

W tabeli 8 przedstawiono produkcję energii elektrycznej z odnawialnych źródeł energii dla Estonii.

Tabela 8. Odnawiane źródła energii
Table 8. Renewable sources

	2004	2020
Lądowe elektrownie wiatrowe	6,7 MW / 7,6 GWh	580 MW / 700 GWh
Elektrownie wiatrowe na morzu	0 MW / 0 GWh	0 MW / 0 GWh
Energia słoneczna	0 MW / 0 GWh	0,5 MW/0,5 GWh

Przykładowo na rysunku 4 przedstawiono zapotrzebowanie na moc elektryczną na tle mocy elektrycznej z elektrowni wiatrowych w Zachodniej Danii. W nocy z 29 na 30 października cała energia elektryczna dla zachodniej Danii produkowana była z elektrowni wiatrowych. Rysunek ten wskazuje na konieczność takiej organizacji produkcji energii elektrycznejw skali lokalnej, regionalnej oraz w skali miedzynarodowej tak aby odnawialne źródła energii elektrycznej mogły pracować przez możliwie długi okres w ciągu doby.



Rys.4. Moc i zapotrzebowanie na energię elektryczną w Zachodniej Danii
Fig.4. Electricity demand and production in West Denmark

4. ENERGETYKA WODNA

Moc elektryczna przekazywana do sieci elektrycznej z elektrowni wodnych w dużym stopniu zależy od ilości opadów. W przypadku lat o obfitych opadach tzw. „mokre" lata ilość energii elektrycznej produkowanej w elektrowniach wodnych wzrasta dla „suchych" lat a więc o małej ilości opadów produkcja energii elektrycznej z elektrownii wodnych maleje

W Polsce średnia produkcja energii elektrycznej z elektrowni wodnych wynosi około 3,5 TWh/rok. W Polsce wykorzystane jest około 12 % potencjału hydroenergetycznego.

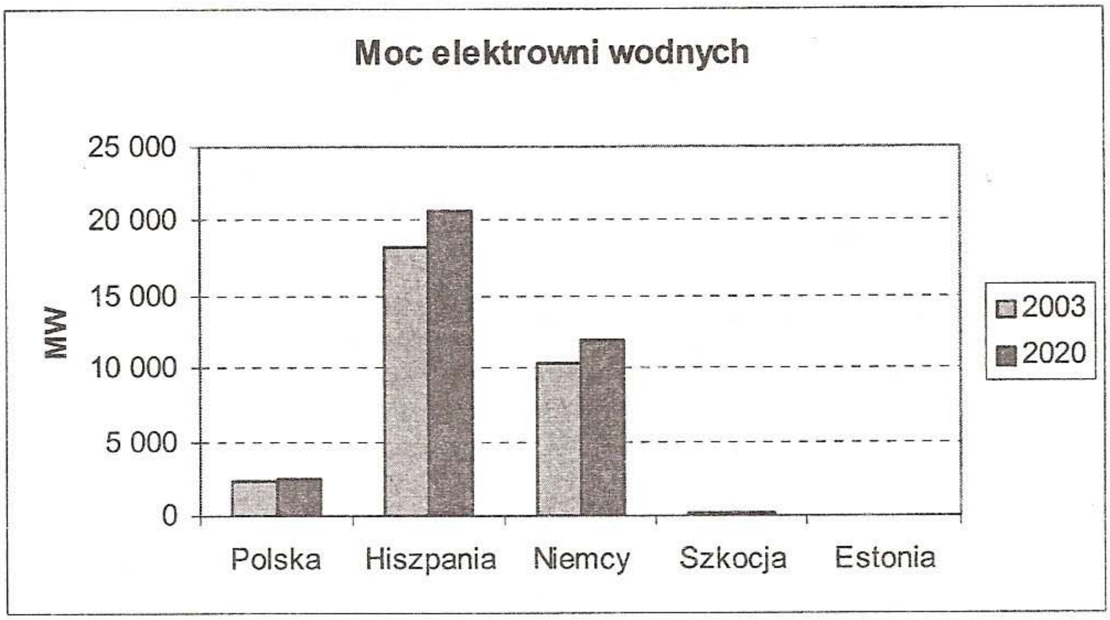
W Danii brak jest elektrowni wodnych.

W Hiszpanii średnia produkcja energii elektrycznej z elektrowni wodnych wynosiła 35,9 TWh/rok. Dla lat obwitych w opady produkcja energii elektrycznej z elektrowni wodnych wzrasta do poziomu 40 TWh w lat uboższych w opady produkcja energii elektrycznej spada do poziomu 30 TWh.

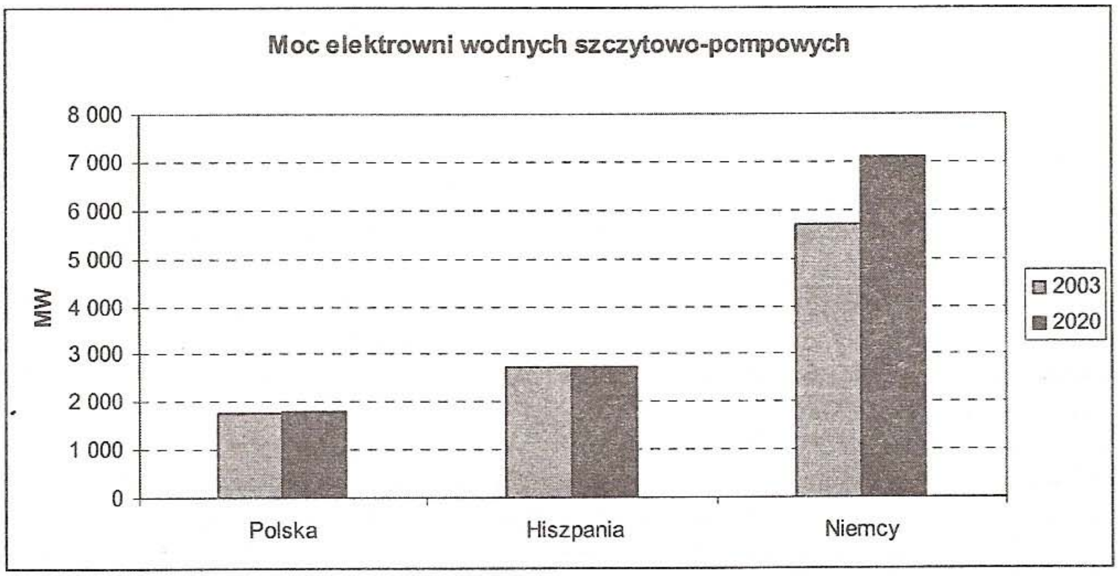
W Niemczech od 1993 roku moc zainstalowana w elektrowniach wodnych jest na stałym poziomie i wynosi 9 GW. W zależności od ilości opadów moc elektryczna produkowana przez elektrownie wodne ulega wahaniom między 19,2 TWh w 1991 roku a 27,7 TWh w roku 2000.

Potencjał rzek w Szkocji został już praktycznie wykorzystany przez energetykę wodną i dlatego przewiduje się nieznaczny wzrost mocy zainstalowanej w elektrowniach wodnych do roku 2020. W Szkocji są tylko elektrownie wodne zbiornikowe.

W Estonii moc zainstalowana w elektrowniach wodnych w 2003 roku wynosiła 4,1 MW a produkcja 22,4 GWh. W 2020 roku planuje się, że moc zainstalowana elektrowniach wodnych wzrośnie do 10 MW a produkcja do 50 GWh.



Rys.5. Moc elektrowni wodnych w MW w poszczególnych krajach (w roku 2003 i zamierzenia w 2020)
Fig.5. Hydro plants power (MW) in specify countries (in 2003 and intentions in 2020)



Rys.6. Moc elektrowni wodnych szczytowo-pompowych w MW w poszczególnych krajach (w roku 2003 i zamierzenia w 2020)
Fig.6. Hydro plants power with reverse pumping and pump storage (MW) in specify countries (in 2003 and intentions in 2020)

5. ENERGETYKA JĄDROWA

Obecnie w Polsce nie ma elektrowni jądrowej jednak w dokumencie rządowym Polityka Energetyczna Polski na lata 2005 – 2025 zakłada się budowę takiej elektrowni w 2021 roku. Elektrowni jądrowych nie ma również na terenie Danii i do roku 2020 nie planuje się budowy tego typu źródeł energii. W Hiszpanii jest siedem elektrowni jądrowych z dziewięcioma reaktorami. Zakłada się, że zainstalowana moc w elektrowniach jądrowych nie zmieni się do roku 2020. W Szkocji działają dwie elektrownie jądrowe o mocy 1 190 MW i 1 250 MW. Zakłada się, że obie elektrownie będą działać po 2020 roku. W scenariuszu „ekologicznym" dla Niemiec zakłada się drastyczną redukcje mocy zainstalowanej w elektrowniach jądrowych z 23 600 MW w 2004 do 6 000 MW w roku 2020.

6. PODSUMOWANIE

W artykule przedstawiono obecną sytuację źródeł wytwarzających energię ze szczególnym uwzględnieniem odnawialnych źródeł energii. Przedstawiono również ogólne założenia tychże krajów do roku 2025 dotyczące produkcji energii ze szczególnym wykorzystaniem elektrowni wiatrowych. Część zamierzeń wydaje się dość trudna do zrealizowania, przede wszystkim, jeśli chodzi o energetykę odnawialną. Sytuacje na rynkach energii w poszczególnych krajach biorących udział w projekcie DESIRE znacznie się różnią. Różnice te wynikają w głównej mierze z zasobów surowcowych poszczególnych krajów, tradycji wytwarzania energii elektrycznej jak również w przypadku energetyki odnawialnej położenie geograficzne krajów, które ma wpływ na potencjał energetyki słonecznej wiatrowej i wodnej.

THE COMPARISON OF THE ELECTICITY MARKET IN CAUNTRIES TAKING PART IN DESIRE PROJECT

SUMMARY

The situations of energy market in the countries participate in DESIRE project are different. In this paper the situation sources of energy, especially renewable sources of energy are presented. Energy assumptions these countries till 2025 with special including renewable sources of energy are shown. The part of these assumptions are very difficult to execute.

Dissemination strategy on Electricity balancing
DESIRE
large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Krzysztof Wojdyga, Marcin Lec, Rafal Laskowski Warszaw University of Technology
E-mail	krzysztof.wojdyga@is.pw.edu.pl
Title of dissemination	Dissemination strategy on electricity balancing for large scale integration of renewable energy - DESIRE Project.
Type of activity	Presentation at conference Article in conference proceedings
Title of forum	I International Conference on Solar Energy and Ecobuildings. RENEWABLE ENERGY - Innovative ideas and technologies for buildings.
Language	Polish
Date of dissemination	May 17 – 20 , 2006
Place of dissemination	Solina Poland
Brief abstract / description of dissemination activity	DESIRE will disseminate practices which will integrate fluctuating renewable electricity supplies such as wind power into electricity systems using combined heat and power. This integration will make possible an increase in pan-European trade in electricity, it will improve the economic competitiveness of both CHP and wind power and it will increase the ability of electricity system operators to handle increasing quantities of electricity generated by decentralized sources.
Audience impact assessment	Article presentation on the conference was received with great interest. Discussion was connected to problems of developing national renewable resources in connection with combine heat and electricity production. Article has been published in conference proceedings prepared by Resovia University of Technology "Folia Scientiarum Universitatis Resoviensis". Conference materials consist of 79 articles connected to renewable energy sources.
Dissemination	Included after this form

Pierwsza Międzynarodowa Konferencja Energii Słonecznej
i Budownictwa Ekologicznego
ENERGIA ODNAWIALNA
Innowacyjne idee i technologie dla budownictwa
SOLINA 2006

Krzysztof WOJDYGA, dr inż.
Rafał LASKOWSKI, mgr inż.
Marcin LEC, mgr inż.

Politechnika Warszawska
Wydział Inżynierii Środowiska i Mechaniczny Energetyki i Lotnictwa
ul. Plac Politechniki 1, 00-661 Warszawa
e-mail: krzysztof.wojdyga@is.pw.edu.pl

ROZPOWSZECHNIENIE NA DUŻĄ SKALĘ STRATEGII BILANSOWANIA ENERGII ELEKTRYCZNEJ PRODUKOWANEJ W ODNAWIALNYCH ŹRÓDŁACH ENERGII - DESIRE

STRESZCZENIE

DESIRE ma za zadanie określenie możliwości współpracy odnawialnych źródeł energii elektrycznej, jakimi są elektrownie wiatrowe ze źródłami skojarzonej produkcji energii elektrycznej i ciepła (CHP) w systemie elektroenergetycznym. Taka współpraca źródeł stworzy nowe możliwości i zwiększy potencjał handlu energią elektryczną na rynku energii w Europie, co znacznie poprawi finansową (ekonomiczną) konkurencyjność obu źródeł energii tzn. źródeł skojarzonych wytwarzających energię elektryczną i ciepło i elektrowni wiatrowych. Zwiększy się również zdolność zagospodarowania przez operatorów systemów elektroenergetycznych rosnących ilości energii elektrycznej generowanej w rozproszonych (zdecentralizowanych) źródłach.

1. WPROWADZENIE

Projekt DESIRE ma na celu zbadanie możliwości bilansowania energii elektrycznej, która będzie równoważyła wahania w produkcji energii elektrycznej ze źródeł odnawialnych takich jak elektrownie wiatrowe w systemie elektroenergetycznym. Zadanie równoważenia produkcji pełnić mogą konwencjonalne skojarzone źródła wytwarzające energię elektryczną i ciepło.

Projekt jest realizowany jako projekt w 6 Programie Ramowym związany z programem „Integrating and Strengthening the European Research Area" a w szczególności z priorytetem 6.1.3.1.1.2 „Large scale integration of renewable energy sources into energy supplies". Jest również związany tematycznie z priorytetem „efektywności ekonomicznej energetyki wiatrowej" (6.1.3.1.1.1).
Projekt ten jest zgodny z polityką energetyczną Unii Europejskiej i jest związany z wdrażaniem dyrektyw europejskich dotyczących rynku energii elektrycznej i energii odnawialnych. A w szczególności z Dyrektywę 2003/54/EC z 26 czerwca 2003 roku dotyczącej „wspólnych zasad na wewnętrznym rynku energii elektrycznej zmieniającej dyrektywę 96/92/EC. Zadaniem tej dyrektywy jest stworzenie bardziej konkurencyjnego europejskiego rynku energii elektrycznej. W przypadku energii odnawialnej, jaką jest energia elektryczna produkowana z wiatru już obecnie w Danii, północnych Niemczech występują problemy z nadmierną produkcją takiej elektryczności. W Danii niekiedy nawet 50 % produkowanej energii elektrycznej pochodzi z farm wiatrowych. Występujące „wąskie gardła" w systemie przesyłowym nie zawsze pozwalają przesłać nadwyżki do innych systemów elektroenergetycznych.
Kolejną dyrektywą jest dyrektywa 2004/8/EC w sprawie promowania kogeneracji w oparciu o zapotrzebowanie na ciepło użytkowe na wewnętrznym rynku energii oraz wnosząca poprawki do Dyrektywy 92/42/EEC. Dyrektywa stwarza warunki dla promocji skojarzenia w ciepłownictwie w tym skojarzenia rozproszonego i wykorzystującego OZE. Dyrektywa ta przewiduje mechanizmy wspierania energetyki skojarzonej między innymi: możliwość udzielenia bezpośredniego lub pośredniego wsparcia mogącego wywierać ograniczony wpływ na handel energią elektryczną oraz konieczność zapewnienia sprawnego przesyłu i dystrybucji energii elektrycznej wytworzonej w skojarzeniu.
Projekt związany jest również z wdrożeniem dyrektywy 2001/77/EC dotyczącej „promowania energii elektrycznej wyprodukowanej z odnawialnych źródeł energii na wewnętrznym rynku energii elektrycznej", której głównym zadaniem jest osiągnięcie 22 % zużycia energii elektrycznej pochodzącej z odnawialnych źródeł energii w krajach Unii do roku 2010.

2. ZADANIA PROJEKTU

Projekt ten będzie promował współpracę elektrociepłowni (CHP) i odnawialnych źródeł energii (RES) tak, aby znaleźć optymalny sposób produkcji energii elektrycznej w tychże odnawialnych źródłach energii dostarczanej do lokalnego lub regionalnego systemu elektroenergetycznego. Pozwoli to na powiększenie pan-europejskiego rynku energii elektrycznej, poprawi konkurencyjność ekonomiczną zarówno elektrociepłowni jak i układów energetyki wiatrowej. Określi również proporcje energii elektrycznej generowanej w źródłach odnawialnych, jaka może zostać zaabsorbowana przez europejski system elektroenergetyczny. Jeżeli udział energii elektrycznej ze źródeł odnawialnych wzrośnie znacząco, może to być groźne dla europejskiego systemu energetycznego. Elektroenergetyczne połączenia trans-graniczne mogą zostać zablokowane przez przepływ nadmiernej ilości energii elektrycznej z farm wiatrowych.
Problem ten dotknął już Danię a zwłaszcza jej północną część a także Niemcy. Przy bardzo korzystnych warunkach wiatrowych szczególnie w okresie nocnym, kiedy zapotrzebowanie na energię elektryczną znacznie spada, przesyłowa sieć elektryczna nie jest w stanie przesłać dodatkowej dużej porcji energii elektrycznej wyprodukowanej w turbinach

wiatrowych w Schleswig Holstein i na Jutlandii. W projekcie przeanalizowane zostaną możliwe rozwiązania tych problemów w okresach krótko i długo terminowych. Otrzymane wyniki rozpowszechniane będą przez uczestników projektu. Bez wdrożenia wyników tego projektu współpraca odnawialnych źródeł ze źródłami konwencjonalnymi energii elektrycznej będzie trudna a niekiedy niemożliwa. Rozbudowa istniejących połączeń trans granicznych i wzmacnianie lokalnych sieci elektroenergetycznych powinny uwzględniać zagadnienia współpracy tych źródeł energii.. W projekcie DESIRE energetyka odnawialna traktowana jest jako energia produkowana z elektrowni wiatrowych, ale dotyczy to również innych odnawialnych źródeł energii elektrycznej, z których produkcja energii podlega silnym wahaniom, jeśli chodzi o czas i moc generowanej energii elektrycznej.

Obecnie do bilansowania wahań w produkcji energii elektrycznej z odnawialnych źródeł energii używane są wielkie klasyczne elektrownie (węglowe i jądrowe o dużych mocach), których głównym zadaniem jest praca w podstawie systemu elektroenergetycznego. Lepsze efekty regulacyjne będzie można osiągnąć, jeżeli w celu bilansowania produkcji energii elektrycznej używane będą kombinowane układy elektrociepłowni i elektrowni wiatrowych, które będą oferować korzystniejsze warunki na tą usługę na rynku energii niż te oferowane przez wielkie elektrownie.

Te kombinowane układy pozwolą na częściowe zbilansowanie fluktuacji w produkcji energii elektrycznej z elektrowni wiatrowych. Pozwoli to również zapewnić, że większość elektrowni wiatrowych używanych lokalnie nie będzie wpływać negatywnie na system elektroenergetyczny, ale będzie przeciwdziałać przeciążeniu i niedociążeniu sieci elektrycznej. Należy zauważyć, że małe źródła energii elektrycznej mogą zaspokajać lokalne potrzeby, które do tej pory zasilane były z dużych elektrowni. Dlatego też małe źródła energii elektrycznej mogą zwiększyć konkurencyjność dostarczanej energii, pozwoli to również na podwyższenie jakości energii elektrycznej i stabilności pracy systemu elektroenergetycznego. Układy kombinowane elektrociepłowni i elektrowni wiatrowych stwarzają dużo bardziej atrakcyjne i efektywniejsze finansowo warunki zasilania w energię elektryczną na wszystkich rynkach energii elektrycznej, spowodować to może, ze układy te staną się jeszcze bardziej konkurencyjne na rynku energii elektrycznej Unii Europejskiej. Powinno to również wpłynąć na obniżenie cen dla odbiorców i znaczną poprawę jakości zasilania w energię elektryczną.

Systemy elektrociepłowni współpracujące z elektrowniami wiatrowymi w produkcji i bilansowaniu energii są bardziej przewidywalne, mogą zasilać odbiorców w energię elektryczną i ciepło. Układy takie muszą być powiększone o dodatkowe urządzenia, które pozwolą na magazynowanie energii cieplnej albo urządzenia pozwalające na wykorzystanie energii elektrycznej, która w danym okresie jest produkowana w nadmiarze.

W przypadku nadmiernej produkcji energii elektrycznej z elektrowni wiatrowych, elektrociepłownia zmniejsza produkcję energii elektrycznej a jednocześnie zaspakaja potrzeby cieplne mieszkańców i dodatkowo doładowuje zasobnik ciepła. Jeżeli wystąpi konieczność wyłączenia produkcji energii elektrycznej przez elektrociepłownię odbiorcy ciepła zasilani będą z zasobnika ciepła. Kiedy produkcja energii z elektrowni wiatrowych jest nadmierna, a elektrociepłownia już nie produkuje prądu „wiatrowa" energia elektryczna będzie zamieniana przez pompę ciepła w ciepło i będzie zasilała lokalnych odbiorców lub alternatywnie będzie doładowywała zasobniki ciepła aby mieć zapas na pokrycie przyszłego przewidywanego zapotrzebowania. W sytuacji gdy produkcja energii elektrycznej z elektrowni wiatrowych jest niska, elektrociepłownie operują w kierunku dostarczania ciepła z akumulatorów i pokrywają braki w zasilaniu w energię elektryczną spowodowaną zatrzymaniem się elektrowni wiatrowych.

W celach badawczych „zbudowana" zostanie wirtualna duża elektrownia składająca się z niewielkich elektrociepłowni i farm wiatrowych. A przeprowadzone analizy bazujące na rzeczywistych warunkach pogodowych i rzeczywistych zapotrzebowaniach na energię elektryczna i ciepło wskażą na najbardziej efektywne energetycznie rozwiązania układów wytwórczych.

Profesjonalne oprogramowanie i inne narzędzia informatyczne będą używane do zademonstrowania i upowszechnienia analiz pracy systemów elektroenergetycznych zasilanych ze źródeł odnawialnych dla trzech państw uczestników projektu Danii, Niemiec i Wielkiej Brytanii. Wyniki analiz i symulacji komputerowych pozwolą na wyciągnięcie wniosków dotyczących oddziaływania źródeł energii odnawialnej w pozostałych krajach uczestnikach projektu Hiszpanii, Polski i Estonii. Wyniki projektu będą rozpowszechnione w kręgach zainteresowanych instytucji obecnych na rynku energii, powinny być uwzględnione w rządowych programach rozwoju energetyki. Przewidywane są prezentacje otrzymanych wyników na seminariach i konferencjach naukowych oraz publikacje w prasie fachowej. Utworzona zostanie interaktywna strona internetowa.

Oprócz tego opracowane zostaną materiały obejmujące zagadnienia możliwości projektowania nowych skojarzonych źródeł energii i warunków ekonomicznych, technicznych i prawnych w różnych krajach Europy" – dokument ten opisuje aktualny stan prawny i uwarunkowania ekonomiczne budowy nowych źródeł energii elektrycznej w poszczególnych państwach biorących udział w projekcie DESIRE. Niezależnym dokumentem będzie opracowana koncepcja dla projektowania małych elektrociepłowni CHP dla zespołów budynków lub fabryk oraz średniej wielkości rozproszonych elektrociepłowni, produkujących ciepło i energię elektryczną. Przebadane zostaną techniczne i ekonomiczne wymagania dla optymalizacji projektu pod kątem bilansowania wahań produkcji energii elektrycznej wytwarzanej w elektrowniach wiatrowych.

Projekt DESIRE ma rozpowszechnić opracowaną metodykę postępowania i narzędzia programowe, które będą umożliwiały projektowanie i budowanie małych i średnich rozmiarów elektrociepłowni do kombinowanych lub współpracujących z energetyką odnawialną układów w produkcji energii elektrycznej.

3. OPIS PRACY

Projekt DESIRE jest podzielony na 8 zadań tematycznych - pakietów:

1: Problemy bilansowania energii elektrycznej

W pakiecie tym przeanalizowane będą problemy związane z bilansowaniem produkcji energii elektrycznej z konwencjonalnych i odnawialnych źródeł energii obecnie i w przyszłości z uwzględnieniem przesyłu trans granicznego. Określenie roli układów skojarzonych w bilansowaniu zmian przy produkcji energii elektrycznej z uwzględnieniem uwarunkowań lokalnych.

2: Rozwiązania technologiczne na „dzisiaj i jutro"

W pakiecie tym zaproponowane zostaną proste rozwiązania techniczne, które pozwolą na rozwiązanie problemów bilansowania poprzez stosowanie układów kogeneracyjnych współpracujących z zasobnikami ciepła. Zaprezentowane będą również rozwiązania techniczne układów hybrydowych z zastosowaniem różnych urządzeń takich jak układy skojarzone, ogniwa paliwowe, microturbiny, silniki stirlinga, układy trigeneracyjne, pompy ciepła i zasobniki ciepła. Przeanalizowane zostaną możliwości wykorzystania budynków jako magazynów ciepła. Te rozwiązania techniczne będą rozpatrywane pod kątem ekonomicznym na różnych rynkach energii elektrycznej.

3: Analiza warunków prawnych i ekonomicznych, możliwości i bariery wdrożenia wyników projektu

W pakiecie tym przeanalizowane zostaną uwarunkowania prawne dotyczące zagadnień produkcji energii elektrycznej ze źródeł odnawialnych i skojarzonych w poszczególnych krajach uczestnikach projektu. Określony zostanie stopień implementacji dyrektyw unijnych do prawa krajowego i wpływ tych rozwiązań ekonomiczno- prawnych na możliwości bilansowania energii elektrycznej pochodzącej ze źródeł odnawialnych.

4: Przygotowanie modelu komputerowego „wirtualnej elektrowni", procedur optymalizacyjnych oraz innych narzędzi informatycznych

Ta najważniejsza część projektu bazować będzie na informacjach zebranych i przeanalizowanych w pakietach 1, 2 i 3. Zbudowany zostanie model „wirtualnej elektrowni" składającej się różnych urządzeń wytwórczych współpracujących ze sobą. Program zawierał będzie narzędzia umożliwiające przeprowadzenie szczegółowych analiz zarówno technicznych jak i ekonomicznych.

5: Badania symulacyjne i testowanie programów

Opracowana w WP4 metodyka badań i programy komputerowe będą testowane dla wybranych układów kombinowanych elektrociepłowni i farm wiatrowych w Danii, Niemczech i Wielkiej Brytanii. Na przykładzie tych złożonych układów technologicznych pokazane zostaną możliwości bilansowania energii pochodzącej z różnych źródeł.

6: Podsumowanie i wnioski

W pakiecie tym omówione zostaną wyniki analiz i symulacji z pakietu 5. Określone zostaną możliwe sposoby współpracy układów kogeneracyjnych z układami turbin wiatrowych uwzględniające lokalne uwarunkowania krajowe. Opisane zostaną sposoby promowania układów skojarzonych współpracujących z zasobnikami ciepła. Przygotowane zostaną wnioski dotyczące przyszłych rozwiązań technicznych współpracy elektrociepłowni z odnawialnymi źródłami energii. Przygotowane będą również wnioski dotyczące zmian prawnych w tym zakresie.

7: Strona internetowa projektu

W pakiecie tym uruchomiona zostanie internetowa baza zarządzania projektem i rozpowszechniania informacji o projekcie. Pozwoli ona na sprawne zarządzenie projektem oraz dostęp w czasie rzeczywistym do wszystkich dokumentów projektu dla jego uczestników a dla osób zainteresowanych wynikami projektu dostęp w stopniu ograniczonym.

8: Prezentacja wyników

Prezentacja wyników projektu oparta będzie ona zorganizowaniu kilku seminariów tematycznych w krajach uczestników projektów oraz na publikacji artykułów w prasie fachowej.

Projekt jest projektem zintegrowanym realizowany jako (SSA) Specific Support Action. W projekcie udział biorą wyższe uczelnie techniczne, instytuty naukowe i firmy konsultingowe z branży energetycznej z 6 krajów europejskich. Specyfika produkcji energii elektrycznej i wykorzystanie odnawialnych źródeł energii jest w każdym z tych krajów inne. Z tego też powodu wyniki projektu mogą być wykorzystane w innych krajach Unii Europejskiej. Koordynatorem projektu jest profesor Henric Lund z Uniwersytetu Aalborg w Danii. W poniższej tabeli przedstawiono wszystkich uczestników projektu stronę polska reprezentuje Uczelniane Centrum Badawcze Energetyki i Ochrony Środowiska Politechniki Warszawskiej.

Tabela 1. Partnerzy
Table 1. Partners

L.p.	Nazwa	Kraj
1	Aalborg University, Sustainable Energy Planning Research Group	Dania
2	EMD International A/S	Dania
3	PlanEnergi	Dania
4	University of Birmingham	Wielka Brytania
5	Institut für Solare Energieversorgungstechnik Verein an der Universität Kassel e.V.	Niemcy
6	Universität Kassel	Niemcy
7	EMD Deutschland, Chun und andere GBR	Niemcy
8	Fundación Labein	Hiszpania
9	**Politechnika Warszawska**	**Polska**
10	Tallin University of Technology	Estonia

4. PODSUMOWANIE

Opracowanie skutecznej metody współpracy elektrociepłowni i elektrowni wiatrowych oznacza, że elektrownie te mogą pracować z maksymalnymi mocami i utrzymywać wysoką niezawodność zasilania w energię elektryczną. Duża liczba elektrowni wiatrowych, ale działających pojedynczo, może tworzyć duże problemy a niekiedy wręcz zagrożenie dla stabilnej pracy lokalnego systemu elektroenergetycznego, które może być przeniesione na system ponad regionalny.

W ramach projektu realizowanego w 8 pakietach wykonane zostaną analizy stanu obecnego rynku energii elektrycznej i możliwe do wystąpienia w następnych latach scenariusze. Wykonane symulacje komputerowe dla wybranych rynków energii pozwolą na wybór optymalnych rozwiązań zarówno technicznych, prawnych i ekonomicznych umożliwiających skuteczne bilansowanie wahań przy produkcji energii elektrycznej w odnawialnych źródłach energii uwzględniając przy tym specyficzny stan w poszczególnych krajach. Wyniki projektu mogą również wpłynąć na zmiany w prawie krajowym jak również mogą pomóc w kształtowaniu dyrektyw Unii Europejskiej.

DISSEMINATION STRATEGY ON ELECTRICITY BALANCING FOR LARGE SCALE INTEGRATION OF RENEWABLE ENERGY - DESIRE

SUMMARY

DESIRE will disseminate practices which will integrate fluctuating renewable electricity supplies such as wind power into electricity systems using combined heat and power. This integration will make possible an increase in pan-European trade in electricity, it will improve the economic competitiveness of both CHP and wind power and it will increase the ability of electricity system operators to handle increasing quantities of electricity generated by decentralized sources.

Dissemination strategy on Electricity balancing
DESIRE
large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Krzysztof Wojdyga, Malgorzata Kwestarz Warsaw University of Technology
E-mail	krzysztof.wojdyga@is.pw.edu.pl
Title of dissemination	Energy storage in view of cogeneration systems generating heat and electricity.
Type of activity	Presentation at conference Article in conference proceedings Article in journal "District Heating, Heating and Ventilation".
Title of forum	XV National Conference of District Heating X Forum of Polish District Heating Engineers
Language	Polish
Date of dissemination	September 17 – 20 , 2006
Place of dissemination	Miedzyzdroje Poland
Brief abstract / description of dissemination activity	The problems of energy storage are presenting regarding various form of energy. Considerable attention is given to thermal energy. A model of energy production (including electricity, heat and cool) has been defined. The energy storage and mutual energy conservation possibilities are also described. Examples of the existing systems are given. Concluding remarks show potential technical and economical advantages resulting from the exploitation of heat storage bins.
Audience impact assessment	Article has been published at conference materials. The conference materials were distributed for 400 conference participants and send to DHC members of Chamber of Commerce Polish District Heating. During the conference we have discussed problems connected to heat storage and directions of developing district heating systems using small CHP. We have got proposal to publish article in technical journal. Article has been published in conference proceedings prepared by Chamber of Commerce Polish District Heating Conference materials consist of 43 articles connected to district heating. Article has been published in technical journal "District Heating, Heating and Ventilation". No. 1 (442) Warsaw, January 2007. Journal is edited monthly by Polish Association of Sanitary Engineers and Technicians. www.cieplogaz.com.pl
Dissemination	Included after this form

Miesięcznik
Polskiego Zrzeszenia
Inżynierów i Techników
Sanitarnych

Rok założenia 1969

Źródła ciepła, energetyka, ciepłownictwo, sieci i węzły cieplne, stacje przetwarzające, instalacje centralnego ogrzewania i ciepłej wody użytkowej, wentylacja, klimatyzacja, wentylacja przemysłowa, odciągi miejscowe, transport pneumatyczny, instalacje przemysłowe, wymiana ciepła, fizyka ustrojów budowlanych, odzyskiwanie ciepła, chłodnictwo, automatyzacja systemów i urządzeń cieplnych oraz powietrznych.

Adres Redakcji:
CIEPŁOWNICTWO, OGRZEWNICTWO, WENTYLACJA
ul. Czackiego 3/5, pokój 216
00-950 Warszawa, skr. poczt. 1004,
tel./fax (0-22) 828-27-26, tel. (0-22) 826-43-35
tel. (0-22) 336-13-19

INTERNET: www.cieplogaz.com.pl
e-mail: cieploogrzewwent@sigma-not.pl
e-mail: redakcja.cow@neostrada.pl
e-mail: cow@cieplogaz.com.pl

ISSN 0137-3676

Wydawnictwo Czasopism i Książek Technicznych

SIGMA NOT

Spółka z o.o.

ul. Ratuszowa 11, 00-950 Warszawa, skr. poczt. 1004
tel.: (0-22) 818-09-18, 818-98-32, fax 619-21-87
Internet: http://www.sigma-not.pl
Prenumerata e-mail: kolportaz@sigma-not.pl
Informacje e-mail: informacja@sigma-not.pl

Skład i druk: Drukarnia SIGMA-NOT Sp. z o.o.
e-mail: drukarnia@drukarnia.sigma-not.pl
Nakład: do 3000 egz., Cena zł 16,00 (VAT „0")

W NUMERZE 1/2007

CIEPŁOWNICTWO

Magazynowanie energii a układy skojarzonego wytwarzania energii elektrycznej i ciepła – ***dr inż. Krzysztof Wojdyga, mgr inż. Małgorzata Kwestarz*** . . . 3

Algorytmy bilansowania energii odnawialnej dla złożonych struktur wielopaliwowych elektrociepłowni przemysłowo-komunalnych – ***dr inż. Jarosław Zuwała*** . . . 10

Pola prędkości w kanałach rekuperatora spiralnego o przepływie wzdłużnym typu WS – ***Mariusz Adamski*** . . . 15

WYMIANA CIEPŁA

Porównanie klasycznej i zmodyfikowanej metody impulsowej do wyznaczania dyfuzyjności cieplnej metali na przykładzie żelaza elektrolitycznego. Część I – ***prof. dr hab. inż. Janusz Terpiłowski, mgr inż. Joanna Piotrowska – Woroniak, mgr inż. Grzegorz Woroniak*** . . . 17

OGRZEWNICTWO

Współczynnik wzmocnienia przy ogrzewaniu dyżurnym – ***Ryszard Śnieżyk*** . . . 22

Optymalne usytuowanie kolektora słonecznego – ***dr inż. Małgorzata Basińska, mgr inż. Łukasz Bobryk, prof. dr hab. inż. Halina Koczyk*** . . . 26

Obliczanie projektowej straty ciepła przez przenikanie wg PN-EN 12831 – ***dr inż. Michał Strzeszewski*** . . . 31

WSPOMNIENIE

Profesor OLE FANGER nie żyje (1934-2006) – ***prof. Bogdan Mizieliński*** . . . 35

PORADNIK PROJEKTANTA – mgr inż. Jerzy Kosieradzki JK Doradca

Nowe normy i co dalej? . . . 36

TARGI

POLEKO międzynarodowe nie tylko z nazwy . . . 37

NOWOŚCI TECHNICZNE

Współpracuje ze słońcem – ***en***. Inteligentne ogrzewanie – ***Wojciech Niemiec*** . . . 38

NOWE NORMY

Normy obowiązujące od sierpnia 2006 r. – ***en*** . . . 39

CZY WIESZ ŻE...

Ciepło z odzysku odpadów . . . 14

Nagrody Ministra Budownictwa 2006 . . . 39

Z ŻYCIA ZRZESZENIA

Plan imprez naukowo-technicznych na rok 2007 – Polskie Zrzeszenie Inżynierów i Techników Sanitarnych Oddział w Katowicach . . . 40

FELIETON TECHNICZNY

Matura i co z niej wynika – ***Jerzy Kosieradzki*** . . . III okł.

CONTENTS

Energy Storage in View of Associated Systems Generating Heat and Electric Energy – ***Krzysztof Wojdyga, Małgorzata Kwestarz*, page 3**

The problems of energy storage are presented regarding various form of energy. Considerable attention is given to thermal energy. A model of energy production (including electricity, heat, and coolness) has been defined. The energy storage and mutual energy conversion possibilities are also described. Examples of the existing systems are given. Concluding remarks show the potential technical and economic advantages resulting from the exploitation of heat storage bins.

The paper has been published among the Conference Materials of the X Forum of Polish District Heating Engineers in Międzyzdroje 2006.

Balancing Algorithms of Renewable Energy for Complex Structures in Multifuel CHP Plants – ***Jarosław Zuwała*, page 10**

Cofiring of the biomass with the conventional fossil fuels is a kind of technology that has been developing dynamically in Poland during the last two years. Selected issues are presented in the paper, connected with the production of the renewable energy in the industrial and municipal thermal-electric multifuel CHP plants with complex technological structures. The balancing algorithms, concerning the amount of the renewable energy, produced during co-firing of the biomass and the conventional fuels, are presented. A simplified methodology, enabling determination of the net calorific value of the gas fuels used in the co-firing processes, is discussed.

Velocity Fields in Ducts of Spiral Recuperator of WS Type with Longitudinal Flow – ***Mariusz Adamski*, page 15**

The velocity field was simulated in the ducts of a spiral recuperator with longitudinal counterflow. The ANSYS v. 8.1 program was used. The task of the field modelling was considered for a real fluid. Simplified assumptions, concerning the geometry of the recuperator, were given, and the form of the recuperator channel was reduced to a rectangle.

The boundary conditions were determined. The calculations were carried out for the geometrical dimensions assumed. The stream function and the velocity field were found. The paper presents the results in a graphic form. The velocity field obtained accounts for the difference between the estimated resistance of the flow and the measurement results achieved.

Comparison of Classic and Modified Flash Methods for Determining Thermal Diffusivity of Metals with a Sample of Electrolytic Iron as an Example. Part I – ***Janusz Terpiłowski, Joanna Piotrowska-Woroniak, Grzegorz Woroniak*, page 17**

A short review of contemporary methods, concerning determination of thermal diffusivity, is presented. The classic and modified flash methods, as applied by the authors, are described, including an experimental stand and adequate procedures (Part I).

Part II will contain the results of the author's investigations of the thermal diffusivity, taking as an example a standard sample of electrolytic iron (NBS – Research material 8421 Electrolytic Iron). An evaluation method of measurement error for the modified method will also be included.

Optimal Location for Solar Collector – ***Małgorzata Basińska, Łukasz Bobryk, Halina Koczyk*, page 26**

The aim of the paper is to found the optimal location of a solar collector. The location is determined by the direction and inclination angle of the collector, in relation to the four cardinal points, by using the method of isotropic sky and anisotropic sky. The basis of the analyses is the data, concerning the total solar radiation on a horizontal surface, obtained in 1997at a measuring stand of external climate in Poznan University of Technology [1].

Calculation of Designed Losses of Heat Penetration According to PN-EN 12831 Standard 12831 – ***Michał Strzeszewski*, page 31**

A method of calculation, concerning the designed losses of heat penetration according to the PN-EN 12831 Standard, is presented.

***Tłumaczył*: mgr inż. Zbigniew Tymowski**

Magazynowanie energii a układy skojarzonego wytwarzania energii elektrycznej i ciepła

Dr inż. KRZYSZTOF WOJDYGA
Mgr inż. MAŁGORZATA KWESTARZ
Instytut Ogrzewnictwa i Wentylacji
Politechniki Warszawskiej

Przedstawiono skrótowo zagadnienia magazynowania energii w różnych postaciach, ze szczególnym uwzględnieniem aspektów magazynowania ciepła. Zdefiniowano model produkcji energii elektrycznej, ciepła i chłodu, możliwości ich magazynowania oraz wzajemnej konwersji. Przytoczono przykłady istniejących instalacji, a na zakończenie pokazano potencjalne korzyści techniczno-ekonomiczne wynikające z eksploatacji zasobników ciepła.

Artykuł zamieszczono w materiałach konferencyjnych X Forum Ciepłowników, Międzyzdroje 2006

PODJĘTO próbę przedstawienia zagadnień związanych z wytwarzaniem i akumulowaniem energii. Potocznie akumulacja kojarzona jest z magazynowaniem energii elektrycznej w akumulatorach, ciepła w zbiornikach zwanych zasobnikami ciepła bądź chłodu w postaci, tzw. wody lodowej. Przykładami doskonale znanym są także hydroelektrownie wyposażone w górne zbiorniki retencyjne, urządzenia procesowe elektrolizy wody do postaci czystego tlenu i wodoru, a następnie stosowanie ich jako paliwa do ogniw paliwowych lub też pompy ciepła bądź kotły elektryczne transponujące energię elektryczną na ciepło i alternatywnie chłodziarki absorpcyjne transponujące energię elektryczną i ciepło na chłód.

Produkcja energii elektrycznej i ciepła

Produkcja energii elektrycznej i ciepła jest zagadnieniem złożonym obejmującym zarówno gospodarkę paliwem, eksploatację różnorodnych układów produkcyjnych, jak i szeroki wachlarz metod transformacji i magazynowania energii. Na rysunku 1 przedstawiono schemat modelu opisującego proces wytwarzania energii elektrycznej i ciepła. Analiza prowadzi od zdefiniowania źródeł, czyli energii wodnej, paliw kopalnych oraz energii odpadowej, w tym także odnawialnej, a kończy się określeniem charakterystyki potrzeb rynku energii elektrycznej, ciepła i chłodu. Pomiędzy źródłem energii a jej konsumentem następuje skomplikowany system bilansujący podaż i popyt, niwelujący dysproporcje pomiędzy wielkością aktualnie produkowaną a odbieraną przez konsumentów.

Zależności rozpatrywane są w zakresie dwóch mediów:

- energii elektrycznej wytwarzanej w elektrowniach wodnych, elektrowniach konwencjonalnych oraz układach skojarzonych,
- ciepła produkowanego przez układy skojarzonego wytwarzania i ciepłownie lub kotłownie.

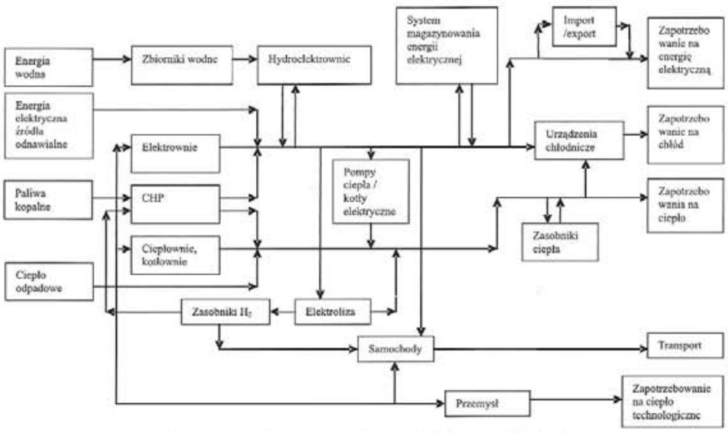
Dodatkowo pojawia się chłód jako czynnik produkowany z wykorzystaniem energii elektrycznej i ciepła. Tak rozbudowany model służy do symulacji komputerowych mających na celu zoptymalizowanie procesów bilansowania produkcji energii w różnych postaciach [1].

Optymalizacja ma charakter wielokryterialny. Upraszczając poszukuje się maksymalnej sprawności wytwarzania przy utrzymaniu na najniższym, możliwym poziomie kosztów produkcji energii elektrycznej, ciepła i chłodu.

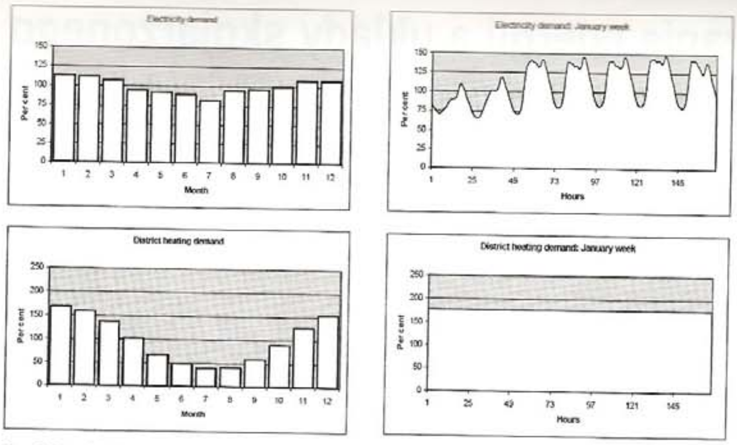
Elementem często pomijanym w gospodarce energetycznej jest transport samochodowy i silniki samochodowe elektryczne lub hybrydowe. Jest to nisza rynku, która może z powodzeniem odbierać i konsumować nadwyżki produkcyjne energii elektrycznej. Odzyskiwanie energii z grupy „samochody" jest także możliwe w funkcji ograniczenia zużycia paliw kopalnych, czyli pochodnych ropy naftowej.

Popyt a podaż energii elektrycznej i ciepła

Zapotrzebowanie na energię elektryczną kształtowane jest przede wszystkim przez przemysł i jego zmianowy charakter pracy. Nie bez znaczenia pozostają także potrzeby komunalno-bytowe takie jak transport, oświetlenie, ogrzewanie lub chłodzenie budynków, a także konsumpcja przez



Rys. 1. Schemat modelu produkcji energii elektrycznej i ciepła



Rys. 2. Przykładowy przebieg zapotrzebowania na energię elektryczną i ciepło (przy wykorzystaniu zasobnika ciepła). Kolumna lewa – profil miesięczny, kolumna prawa – wybrany tydzień stycznia [DESIRE D1.3]

indywidualnych odbiorców. Analizę przebiegu zapotrzebowania na energię elektryczną prowadzi się wyróżniając dni tygodnia od poniedziałku do piątku włącznie i dni weekendowe oraz dzieląc rok kalendarzowy na okres letni i okres zimowy.

Podobnie charakteryzuje się przebieg zmienności zapotrzebowania na ciepło. Czynnikiem wiodącym w przypadku ciepła są oczywiście potrzeby grzewcze budynków mieszkalnych i przemysłowych. Potrzeby grzewcze to ogrzewanie pomieszczeń gdzie stale lub czasowo przebywają ludzie, a także centralne podgrzanie ciepłej wody użytkowej. Dodatkowo do bilansu wprowadza się ciepło na cele technologiczne i jest to na ogół para wodna oraz ciepło przeznaczone do transformacji na chłód w urządzeniach absorpcyjnych. Analogicznie do analizy rynku potrzeb energii elektrycznej, także wyodrębniane są dni tygodnia oraz sezon grzewczy i okres letni. Na rysunku 2 przedstawiono przebiegi zapotrzebowania na energię elektryczną i ciepło.

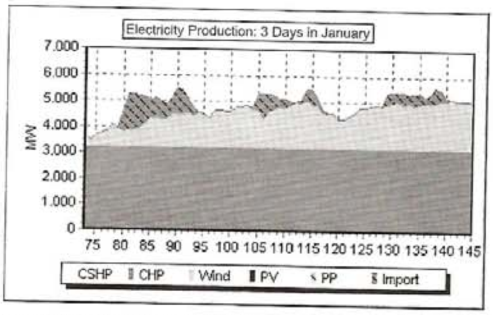
Analiza porównawcza wykresów zapotrzebowania na energię elektryczną i ciepło potwierdza nierównomierność zużycia obu tych mediów, a także duże dysproporcje w konsumpcji w okresie letnim. Optymalna zatem byłaby produkcja dostosowująca się na bieżąco do chwilowych – godzinowych potrzeb rynku. Jednak uwarunkowania technologiczne nie pozwalają na taką regulację podaży, a wręcz przeciwnie, produkcja energii elektrycznej i ciepła na stałym poziomie jest produkcją o najwyższej sprawności, a zatem najtańszą.

Wykorzystanie odnawialnych źródeł energii także stwarza konieczność niwelacji nierównomierności produkcji w tych źródłach. Na rysunku 3 przedstawiono przebieg profilu produkcji energii elektrycznej z farmy wiatrowej i układu solarnego, czyli kolektorów słonecznych.

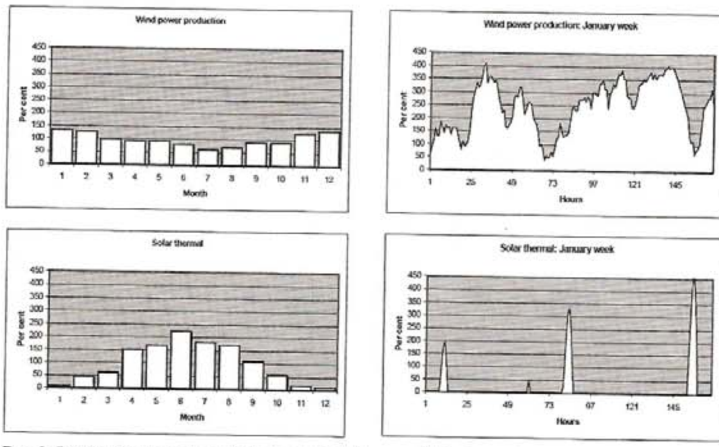
W efekcie otrzymujemy układ, gdzie po stronie źródeł energii pojawiają się fluktuacje podaży energii elektrycznej i ciepła ze źródeł odnawialnych, a po stronie popytu nierównomierności wynikające z charakteru potrzeb konsumentów. Na rysunku 4 przedstawiono trzydniowy przebieg produkcji energii elektrycznej w systemie wzajemnie uzupełniających się źródeł.

W przykładzie pochodzącym z duńskiego systemu elektroenergetycznego podstawę stanowią układy skojarzonego wytwarzania ciepła i energii elektrycznej, następnie dopełniają bilans farmy wiatrowe, a szczytowe zapotrzebowanie na energię elektryczną jest praktycznie importowane z pozostałych krajów Unii Europejskiej. W wypadku Polski podobny wykres oparty jest na produkcji w elektrowniach konwencjonalnych spalających węgiel brunatny, a bilans uzupełniają elektrociepłownie węglowe i nieliczne układu CHP spalające gaz ziemny.

W przypadku produkcji ciepła analiza współpracy wielu źródeł jest bezprzedmiotowa, gdyż dystrybucja ciepła ma charakter lokalny. W przytaczanym przykładzie duńskim jest to ciepło produkowane przez układy CHP pracujące w podstawie i magazynowane w wielkokubaturowych zasobnikach ciepła. W przypadku Polski produkcja ciepła w dużych aglomeracjach miejskich odbywa się w elektrociepłowniach węglo-



Rys. 4. Udział poszczególnych źródeł energii elektrycznej w przykładowym profilu produkcji (Wind – farma wiatrowa, *PV* – układy fotowoltaiki, *PP* – elektrownie konwencjonalne)[DESIRE D1.3]



Rys. 3. Przykładowy profil produkcji energii elektrycznej i ciepła w odnawialnych źródłach energii. Kolumna lewa – profil miesięczny, kolumna prawa – wybrany tydzień stycznia [DESIRE D1.3]

wych a w mniejszych systemach ciepłowniczych w kotłowniach węglowych. W systemach lokalnych są to kotłownie gazowe lub olejowe, a w nielicznych przypadkach małe układy CHP, głównie pracujące w zakładach przemysłowych.

Zasobniki ciepła

W omawianym modelu wytwarzania energii w różnych postaciach zasobniki ciepła stanowią jeden z licznej grupy elementów bilansujących rynek ciepła. Są to urządzenia powszechnie stosowane w elektrociepłowniach duńskich, eksploatowane we Francji i Niemczech. W Polsce instalacje wyposażone w zasobnik stanowią ułamek procenta w ogólnej liczbie źródeł ciepła.

Rozpatrując zagadnienie doboru zasobnika dla konkretnego systemu ciepłowniczego i źródła ciepła należy przeanalizować kilka wariantów. Dobór zasobnika sprowadza się do wyznaczenia wielkości objętości czynnej wody. Na ogół stosuje się zbiorniki, tzw. atmosferyczne, co oznacza, że nad zwierciadłem wody panuje małe nadciśnienie wytworzone przez poduszkę pary wodnej lub azot. Typowy zakres temperatury eksploatacyjnej to 90/45 °C, chociaż podwyższone nadciśnienie wywołane poduszką umożliwia podniesienia maksymalnej temperatury do 120 C. Są to urządzenia niskotemperaturowe, co wymaga odpowiedniego włączenia do obiegu wodnego źródła lub sieci ciepłowniczej.

Wariant I – Zasobnik o pełnej akumulacyjności cieplnej stabilizujący pracę źródła, zakłada dobór zasobnika o pojemności cieplnej umożliwiającej pracę ciągłą źródła z mocą odpowiadającą mocy średniej. Pozwala to na konfigurację źródła o mniejszej mocy od mocy szczytowej, a efektem są mniejsze koszty inwestycyjne oraz koszty eksploatacyjne wynikające z możliwości pracy źródła ze stałą, wysoką sprawnością.

Wariant II – Dobór zasobnika z uwzględnieniem pojemności cieplnej zładu systemu ciepłowniczego. Rozwiązanie to wymaga istnienia rozwiązań konstrukcyjnych, tj. układu przewodów łączących zasilenie z powrotem oraz sprawnej automatyki węzłów ciepłowniczych pozwalającej na zwiększanie temperatury wody sieciowej o ok. 5÷10 K.

Wariant III – Maksymalizacja produkcji energii elektrycznej. Wariant ten uwzględnia wpływ struktury taryf dla energii elektrycznej, na czas pracy układu kogeneracyjnego. Istotną rolę odgrywa podział na grupy taryfowe, grupy przyłączeniowe oraz strefy czasowe rozliczeń. W funkcji wymienionych tych trzech składników lokalne przedsiębiorstwo energetyczne ustala ceny zakupu/sprzedaży prądu do sieci elektroenergetycznej. Zazwyczaj wyróżnia się trzy strefy czasowe, tj. szczyt przedpołudniowy i szczyt popołudniowy z największymi cenami jednostkowymi zakupu energii elektrycznej oraz, tzw. pozostałe godziny z ceną jednostkową minimalną. Maksymalizując zysk z produkcji energii elektrycznej w godzinach szczytu źródło obciążone jest mocą maksymalną równą nominalnej. W pozostałych godzinach układ produkcji skojarzonej obciążany jest mocą, która zapewnia możliwość rozładowania zasobnika.

Wariant IV – Minimalizacja kosztów obsługi, zakłada wyłączenie z pracy układu kogeneracyjnego na czas, np. weekendu. Przerwa w pracy źródła energii ma na celu obniżenie kosztów eksploatacji przez redukcję wynagrodzeń, czyli rezygnację z jednej zmiany obsługującej źródło.

Przykłady instalacji

Pimlico w Westminster jest przykładem jednej z najstarszych instalacji współpracującego zasobnika ciepła z systemem ciepłowniczym w Europie, uruchomiony w latach 1950-1952 [2]. System ten pracuje zarówno na potrzeby centralnego ogrzewania jak i przygotowania centralnie ciepłej wody użytkowej dla ponad 10 000 osób (w roku 1951). Rejon zasilany przez Przedsiębiorstwo Pimlico, to obszar o powierzchni 30 akrów (12,14 ha), położony nad brzegami Tamizy, obejmujący obiekty należące do Pimlico Housing Estate, Dolphin Square oraz Russel House – razem ok. 2900 mieszkań. Kalkulacje z okresu budowy i uruchomienia systemu, czyli ok. 1951 roku wykazały następujące zapotrzebowania na moc wyrażone w jednostkach angielskich B. T. U./h (British Thermal Unit; 1B. T. U=1,05506 kJ):

- Obiekty należące ówcześnie do Pimlico Housing Estate:

– zapotrzebowanie do ogrzewania części mieszkalnej	28 170 000
– podgrzanie c.w.u.	12 350 000
– centralne ogrzewanie i przygotowanie c.w.u. dla budynków użyteczności publicznej: szkoły kościół, szpital itp.	6 880 000
razem	**47 400 000**
– po uwzględnieniu współczynnika niejednoczesności 1,1	43 000 000
– straty przesyłu i dystrybucji	1 720 000
– zapotrzebowanie w źródle	**44 720 000**

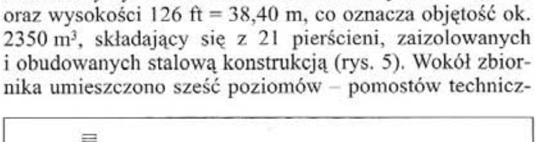
- Obiekty położone na Dolphin Square:

– łącznie oszacowane zapotrzebowanie na c.o. i c.w.u. plus straty	**28 000 000**

Zatem maksymalne zapotrzebowanie na energię w elektrociepłowni szacowano na poziomie **73 000 000 B. T. U. /h, co równa się 21,39 MW.**

System ciepłowniczy składał się ze źródła – elektrociepłowni Battersea – położonego na przeciwległym brzegu rzeki, stacji wymienników, zasobnika ciepła oraz sieci ciepłowniczej wysokoparametrowej zasilającej węzły bezpośrednie lub pośrednie usytuowane w każdym budynku (rys. 5).

Elektrociepłownia Battersea wyposażona była w dwie turbiny parowe przeciprężne o mocy termicznej 1,35 MW każda. Według danych szacunkowych roczna produkcja energii elektrycznej kształtowała się na poziome ok. 9 000 MWh. Para po wyjściu z turbin podlegała schłodzeniu w wymiennikach podgrzewając wodę zasilającą instalacje grzewcze obiektów należących do elektrociepłowni. Przeciwległy brzeg zasilany był magistralą o średnicy d =12 in (300 mm) biegnącą w kanale przełazowym pod dnem Tamizy. Łączyła ona system chłodzenia pary w źródle z pompownią ładująco – rozładowującą zasobnik ciepła. Zbiornik akumulatora zbudowany był w kształcie walca o średnicy 29 ft = 8,84 m oraz wysokości 126 ft = 38,40 m, co oznacza objętość ok. 2350 m³, składający się z 21 pierścieni, zaizolowanych i obudowanych stalową konstrukcją (rys. 5). Wokół zbiornika umieszczono sześć poziomów – pomostów technicz-



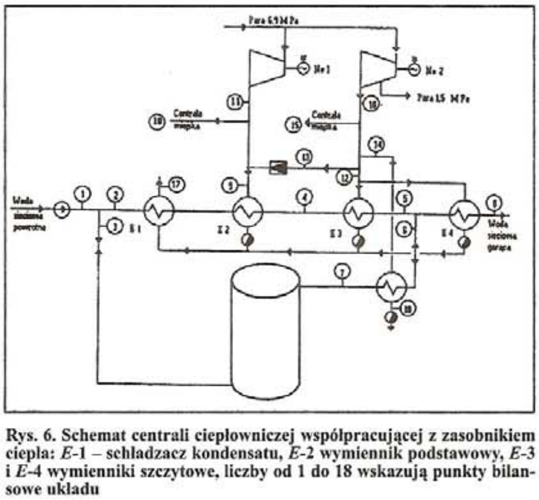
Rys. 5. System ciepłowniczy Pimlico

nych, gdzie znajdowała się aparatura kontrolno-pomiarowa umożliwiająca kontrolę rozkładu ciśnienia i temperatury w zasobniku. Akumulator ten zaprojektowany był jako urządzenie bezciśnieniowe, gdzie gradient temperatury wody wynosił 70÷80 °F, czyli 21÷27 °C. W stacji pomp umieszczono dwa układy pompowe zasilające osiedle Pamlico Housing Estate oraz jeden zestaw przeznaczony do obsługi kompleksu mieszkaniowego Dolphin Square. Zasobnik wraz ze stacją pomp położny był centralnie na obszarze zasilanym przez system ciepłowniczy, co umożliwiło wydzielenie sześciu niezależnych podsystemów zasilania w ciepło. Zadaniem akumulatora ciepła była przede wszystkim stabilizacja obciążenia źródła wobec zmiennych potrzeb cieplnych odbiorców w okresie doby. Ponadto inwestycja w zasobnik była jednym z tańszych rozwiązań zapewniających dostawę ciepła do nowo budowanych osiedli. Do konkurencyjnych projektów z tego okresu należałoby zaliczyć:

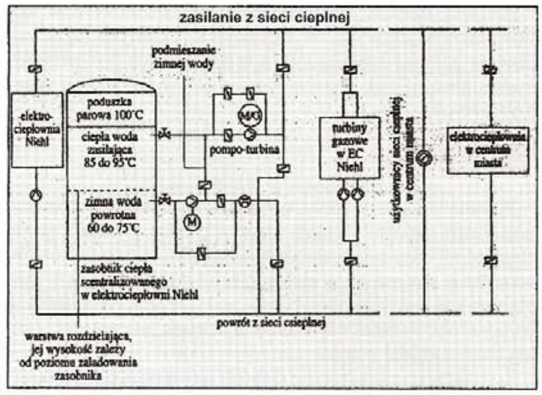
- budowę dodatkowego kotła parowego lub wodnego w istniejącej elektrociepłowni,
- inwestycję w nową elektrociepłownię położoną wśród nowych budynków,
- budowę nowego źródła na bazie pomp ciepła korzystających z ciepła niskotemperaturowego, jakie zapewnia woda z Tamizy.

Przykładem zastosowania akumulatora ciepła w warunkach techniczno-ekonomicznych Polski jest system wody grzewczej w **Zakładach Azotowych „Kętrzyn" S.A., w Kędzierzynie-Koźlu** [3]. Podstawową funkcją zasobnika jest umożliwienie zróżnicowania produkcji energii elektrycznej przez turbozespoły przeciwprężne w elektrociepłowni, zależnie od okresów taryfowych narzuconych przez cennik energii elektrycznej sieci krajowej, przez zmiany w poborze pary dla układów grzewczych Z.A. „Kędzierzyn" S.A. Dodatkowo zasobnik ciepła zwiększa bezpieczeństwo zasilania obiektów Zakładów Azotowych podczas krótkotrwałych awarii źródła ciepła. Schemat podłączenia akumulatora przedstawiono na rys. 1. Zasobnik ciepła w analizowanym przykładzie współpracuje z centralą ciepłowniczą o mocy nominalnej 151 MW, temperaturze wody zasilającej 145 °C / powrotnej 70 °C i przepływie nominalnym 1200 m³/h.

System ten pracuje na potrzeby ogrzewania obiektów należących do Zakładów Azotowych, a zatem w sezonie grzewczym na ogół od października do kwietnia (rys. 6).



Rys. 6. Schemat centrali ciepłowniczej współpracującej z zasobnikiem ciepła: *E*-1 – schładzacz kondensatu, *E*-2 wymiennik podstawowy, *E*-3 i *E*-4 wymienniki szczytowe, liczby od 1 do 18 wskazują punkty bilansowe układu



Rys. 7. Schemat podłączenia zasobnika do sieci ciepłowniczej

Akumulator ciepła składa się z baterii 4 zbiorników o średnicy 5 m i wysokości 26 m każdy, o łącznej objętości 2000 m³. Ciśnienie robocze w zbiornikach wynosi 0,3 MPa nadciśnienia, co umożliwia utrzymanie maksymalnej temperatury wody na poziomie 115 °C. Strumień wody ładującej zasobnik wynosi 200 m³/h, różnica temperatury wody zasilającej i powrotnej wynosi 50 K, co równoważne jest ze zdolnością akumulacyjną 11,2 MW. Średni czas cyklu ładowania i analogicznie rozładowania trwa ok. 9 h. Okres ładowania przypada na taryfę szczytową oraz częściowo dzienną, natomiast rozładowanie odbywa się w trakcie obowiązywania taryfy nocnej. W strukturze zakupu energii elektrycznej przez Z.A. „Kędzierzyn" S.A. taryfa szczytowa wynosi 24,3% udziału czasowego, natomiast nocna 37,5%.

Z analizy techniczno-ekonomicznej wynika, że akumulator ciepła umożliwia przyrost produkcji energii elektrycznej w elektrociepłowni o 4996 MWh w cyklu ładowania zasobnika oraz zmniejszenie o 5133 MWh w cyklu rozładowania. Przy założeniu kosztów inwestycyjnych między 800 a 1 200 tys. zł (w odniesieniu do poziomu cen z 1994 roku), stóp dyskontowych 7-10% oraz okresu eksploatacji 15 lat, NPV utrzymuje wartość dodatnią w całym zakresie cenowym, a IRR waha się od 15 do 25%. Analiza ekonomiczna wykazała jednoznacznie opłacalność inwestycji w przypadku układu grzewczego w Zakładach Azotowych „Kędzierzyn" S.A.

Europejskim przykładem jest system ciepłowniczy miasta Kolonia, należący do multienergetycznego przedsiębiorstwa **Gas – Elektrizitats und Wasserwerke Koln AG (GEW)** [4]. Łączna moc cieplna przyłączeniowa w systemie wynosi 710 MW. Potrzeby odbiorców zaspokajane są z kilku źródeł pracujących na wspólna sieć:

– elektrociepłowni w centralnej części miasta, wyposażonej w turbinę przeciwprężną pokrywającą szczytowe rozbiory ciepła,

– elektrociepłowni Niehl – z parową turbina upustowo-kondensacyjną,

– elektrociepłowni Niehl – instalacji gazowej traktowanej jako źródło szczytowe,

– ciepłowni rezerwowej Deutz.

Moc źródeł wynosi 583,4 MW. Obciążenie z sezonie zimowych osiąga wartości do 450 MW, natomiast w okresie letnim 50 MW.

W systemie tym od 1995 r. pracuje zasobnik ciepła o pojemności 25 000 m³. Jest to przebudowany zbiornik oleju opałowego ciężkiego, który do 1986 roku był wykorzystywany przez elektrociepłownię Niehl. Zasada działania tego obiektu polega na magazynowaniu ciepła w okresach wolnej mocy produkcyjnej w źródle i przekazaniu jej do sieci ciepłowniczej w okresach maksymalnego zapotrzebowania na ciepło (rys. 7).

Akumulator ciepła jest urządzeniem bezciśnieniowym o stałym poziomie wody. Górną część zbiornika wypełnia poduszka parowa. Maksymalny gradient temperatury wody wynosi 35÷38 °C, przy założeniu, że maksymalna temperatura wody zasilającej wynosi 98 °C, a wody powrotnej 60 °C. Maksymalna moc rozładowania równoważna jest przepływowi 2000 m^3/h, co odpowiada ok. 80 MW, moc ładowania jest nieco mniejsza i kształtuje się na poziomie 65MW, co równoważne jest z przepływem 1600 m^3/h.

Poza akumulacją ciepła zasobnik pełni dwie istotne funkcje:

– służy jako zbiornik rezerwowy wody sieciowej przejmując jej nadmiar w systemie, np. na skutek zmian objętości wraz ze wzrostem temperatury,

– stabilizuje ciśnienie w przewodzie powrotnym.

Obie te funkcje są możliwe, gdy akumulator ciepła współpracuje bezpośrednio z obiegami hydraulicznymi sieci przez zespoły pompoturbin i układy zaworów dławiących.

Koszty inwestycyjne adaptacji zbiornika na zasobnik ciepła oraz pozostałych elementów towarzyszących włączeniu do układów hydraulicznych wyniosły ok. 7 mln. DM, a prosty czas zwrotu nie przekroczy 5 lat. Na tak korzystny rachunek ekonomiczny mają wpływ następujące przesłanki:

– zwiększenie produkcji energii elektrycznej w okresach obowiązywania wysokich taryf,

– zastąpienie ciepłowni szczytowych zasobnikiem ciepła,

– wyeliminowanie strat wody uzdatnionej wynikających z odwadniania części instalacji lub rozszerzalności cieplnej wody w systemie.

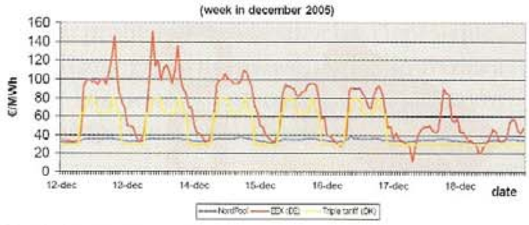
Efekty

W przykładach przytoczono efekty szczegółowe, jakie przyniosło stosowanie zasobników ciepła w konkretnych instalacjach. Natomiast najczęściej stosowanym wariantem doboru zasobnika ciepła jest maksymalizacja produkcji energii elektrycznej w funkcji cen taryfowych – Wariant III. We wspomnianym 6 Programie Ramowym DESIRE [5] analizie szczegółowej poddano cztery struktury cen taryf, powtarzając obliczenia symulacyjne dla tego samego źródła. Modelowym źródłem był układ CHP składający się z czterech silników gazowych o mocach 3 MWth i 2,5 MWee każdy, jednego szczytowego kotła gazowego o sprawności 95%, zasobnika ciepła o pojemności 3600 m^3, co odpowiada 120 MWh. Zapotrzebowanie na ciepła wynosiło 60 000 MWh, w tym 60% przeznaczone na potrzeby c. o. Na rysunku 8 przedstawiono przebiegi cen wg poszczególnych taryf w Niemczech (EXX) i Danii (NordPool i Triple Tariff).

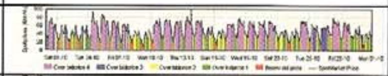
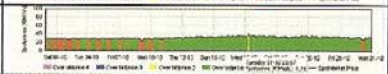
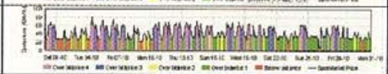
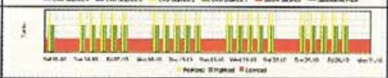
Na rysunku 9 zilustrowano uzyskane rzeczywiste ceny energii elektrycznej uzyskane na rynku bilansującym i dnia następnego w październiku 2005 roku.

Dodatkowo wprowadzano zmienne koszty operacyjne takie jak: koszt paliwa, podatki środowiskowe, OMC silników gazowych i kotła oraz zyski ze sprzedaży energii elektrycznej. Pozostałe koszty uznano jako stałe dla każdej z symulacji.

Najniższy przychód uzyskano stosując mało zróżnicowaną taryfę Nord\Poool charakterystyczną dla systemu skandynawskiego i uznano je, jako poziom odniesienia do pozostałych wyników. Zgodnie z oczekiwaniami, stosowanie w układzie zasobnika ciepła znacząco podwyższa przychody ze sprzedaży energii elektrycznej i zysk z produkcji i sprzedaży ciepła. Najwyższe przychody osiągnięto stosując potrójną taryfę duńską, czyli kontraktując sprzedaż energii na rynku dnia następnego. Przychód względny (odniesio-



Rys. 8. Ceny energii elektrycznej w podziale na godziny doby w wybranym tygodniu [DESIRE D2.2]

Markets	Price Variation October 2005	Average price 2005 €/MWh
EEX		45,0
Nordpool		29,3
Denmark West		37,2
Danish triple tariff		Peak 79,2 High 63,1 Low 29,3

Rys. 9. Uzyskane ceny energii elektrycznej na rynku – październik 2005 [DESIRE D2.2]

ny do poziomu dla taryfy NordPool) dla układu z zasobnikiem wyniósł 1 150 000 Euro, przy jednostkowym zysku z ciepła 19,3 EURO/MWh. Dla porównania przychód w układzie bez zasobnika osiągnął wartość jedynie 550 000 Euro a jednostkowy zysk na cieple zaledwie 9,1 Euro/MWh. Porównywalne wyniki przyniosło stosowanie taryfy niemieckiej EXX z rynku bilansującego. Zysk względny osiągnął poziom 1 130 000 Euro z zasobnikiem i 610 000 Euro bez zasobnika, a jednostkowy zysk z ciepła odpowiednio 18,8 i 10,2 Euro/MW.

Podsumowanie

W artykule zasygnalizowano tematykę, jakiej poświecono 6 Program Ramowy DESIRE. Obecnie może wydawać się, że analiza bilansowania produkcji energii elektrycznej i ciepła w Polsce nie ma istotnego znaczenia ze względu na marginalny udział energetyki odnawialnej, takiej jak: farmy wiatrowe, układy słoneczne itp. Jednak otwarcie granic i handel w skali europejskiej niewątpliwie wymusi podjęcie tego typu działań. Podobnie pozostałe działania unijne, takie jak rozwój handlu emisjami, wprowadzanie świadectw pochodzenia energii, zwiększanie udziału handlu energią w obrocie giełdowym i wygaśnięcie kontraktów długoterminowych czy też stosowanie Dyrektywy o promocji wysokosprawnej kogeneracji, będą sprzyjały poszukiwaniu racjonalnych i efektywnych rozwiązań w zarządzaniu gospodarką energetyczną.

LITERATURA

[1] Program Ramowy UE DESIRE, Munster E.: Deliverable 1.3 Reference Energy PLAN models for all regions for present and for the future, Program na licencji duńskiej EnergyPLAN, UE maj 2006

[2] Margolis A. E.: *Pimlico districtheating scheme* – Journal of Institution of Heating and Ventilating Engineers, kwiecień 1951

[3] Nawrot H.: *Analiza techniczno-ekonomiczna zastosowania akumulatora ciepła w układzie wody grzewczej w Z.A. „Kędzierzyn"* – Gospodarka Paliwami i Energią, 1/1998

[4] Schmidt T., Danda R.: *Budowa i eksploatacja zasobnika ciepła.* Ciepłownictwo w Polsce i na świecie, Rocznik III (1996), zeszyt 11-12 1996

[5] 6 Program Ramowy UE DESIRE, Sievers J., Stadler I., Schmid J.: Deliverable 2.2 Concept for small scale CHP units to be integrated into buildings or industry and medium scale CHP units with disreict heating, UE maj 2006

Dissemination strategy on Electricity balancing

DESIRE

large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Krzysztof Wojdyga, Malgorzata Kwestarz Warsaw University of Technology
E-mail	krzysztof.wojdyga@is.pw.edu.pl
Title of dissemination	Cooperation of associated systems supplying heat engineering plants containing renewable electricity sources.
Type of activity	Presentation at conference Article in conference proceedings Article in journal "District Heating, Heating and Ventilation".
Title of forum	XV National Conference of District Heating X Forum of Polish District Heating Engineers
Language	Polish
Date of dissemination	September 17 – 20 , 2006
Place of dissemination	Miedzyzdroje Poland
Brief abstract / description of dissemination activity	The problems connected with the balancing of the electricity production in wind power plants are presented. The paper takes into account spread cogeneration systems for heat and electricity. The problem is still nonexistent in the Polish market because of the technological aspects of heat and electricity production. However, it is a matter of interest in such countries as Germany, Denmark or Spain. The detail technical and economic analyses are included in the DESIRE 6 FP of the UE General Program.
Audience impact assessment	Article has been published at conference materials. The conference materials were distributed for 400 conference participants and send to DHC members of Chamber of Commerce Polish District Heating. During the conference we have discussed problems connected to cooperation between wind farms and small CHP supplying heat to district heating systems. We have got proposal to publish article in technical journal. Article has been published in conference proceedings prepared by Chamber of Commerce Polish District Heating Conference materials consist of 43 articles connected to district heating. Article has been published in technical journal "District Heating, Heating and Ventilation". No. 11 (440) Warsaw, November 2006. Journal is edited monthly by Polish Association of Sanitary Engineers and Technicians. www.cieplogaz.com.pl
Dissemination	Included after this form

ISSN 0137-3676

CIEPŁOWNICTWO OGRZEWNICTWO WENTYLACJA

NOWOŚĆ od 01.01.2007 PORTAL INFORMACJI TECHNICZNEJ WWW.SIGMA-NOT.PL

WYDAWNICTWO SIGMA NOT

Nr 11 (440) ROK XXXVII

CENA netto 15,00 zł
(w tym „0" VAT)

LISTOPAD 2006

Miesięcznik
Polskiego Zrzeszenia
Inżynierów i Techników
Sanitarnych

Rok założenia 1969

Źródła ciepła, energetyka, ciepłownictwo, sieci i węzły cieplne, stacje przetwarzające, instalacje centralnego ogrzewania i ciepłej wody użytkowej, wentylacja, klimatyzacja, wentylacja przemysłowa, odciągi miejscowe, transport pneumatyczny, instalacje przemysłowe, wymiana ciepła, fizyka ustrojów budowlanych, odzyskiwanie ciepła, chłodnictwo, automatyzacja systemów i urządzeń cieplnych oraz powietrznych.

Adres Redakcji:
CIEPŁOWNICTWO, OGRZEWNICTWO, WENTYLACJA
ul. Czackiego 3/5, pokój 216
00-950 Warszawa, skr. poczt. 1004,
tel./fax (0-22) 828-27-26, tel. (0-22) 826-43-35
tel. (0-22) 336-13-19

INTERNET: www.cieplogaz.com.pl
e-mail: cieploogrzewwent@sigma-not.pl
e-mail: redakcja.cow@neostrada.pl
e-mail: cow@cieplogaz.com.pl

ISSN 0137-3676

Wydawnictwo Czasopism i Książek Technicznych

SIGMA NOT

Spółka z o.o.

ul. Ratuszowa 11, 00-950 Warszawa, skr. poczt. 1004
tel.: (0-22) 818-09-18, 818-98-32, fax 619-21-87
Internet: http://www.sigma-not.pl
Prenumerata e-mail: kolportaz@sigma-not.pl
Informacje e-mail: informacja@sigma-not.pl

Skład i druk: Drukarnia SIGMA-NOT Sp. z o.o.
e-mail: drukarnia@drukarnia.sigma-not.pl
Nakład: do 3000 egz., Cena zł 15,00 (VAT „0")

W NUMERZE 11/2006

CIEPŁOWNICTWO

Współpraca układów skojarzonych zasilających systemy ciepłownicze z odnawialnymi źródłami energii elektrycznej – ***dr inż. Krzysztof Wojdyga, mgr inż. Małgorzata Kwestarz*** 3

Ciepło sieciowe – czysta energia w Energetyce Cieplnej Opolszczyzny – ***mgr inż. Tomasz Piętka, mgr inż. Marcin Porzycki*** 8

LAUR HONOROWY dla prezesa ECO SA 10

Badania szczelności i ubytków wody sieciowej w systemach ciepłowniczych – ***dr inż. Maciej Chorzelski, dr inż. Krzysztof Wojdyga*** 11

OGRZEWNICTWO

Efekty energetyczne i egzergetyczne niskoegzergetycznych układów ogrzewania budynków. Część II: Korzyści i ograniczenia stosowania układów niskoegzergetycznych – ***dr inż. Henryk Foit*** 16

Realizacja postanowień Dyrektywy 2002/91/EC w sprawie charakterystyki energetycznej budynków na przykładzie Białegostoku – ***Cezary A. Pieńkowski*** 20

Dane klimatyczne do obliczeń energetycznych w budownictwie – ***dr inż. Piotr Narowski*** 22

NOWE NORMY

Normy obowiązujące od maja 2006 r. – ***en*** 27

PORADNIK PROJEKTANTA – mgr inż. Jerzy Kosieradzki JK Doradca

Wykres i – x 28

WENTYLACJA. KLIMATYZACJA

Charakterystyki przepływowe łuków $\pi/2$ o przekroju kwadratowym. Część II: Obliczenia numeryczne – ***Michał Szymański, Agata Latusek, Janusz Wojtkowiak*** 29

Wpływ różnych czynników na rozprzestrzenianie się zanieczyszczeń gazowych przy wentylacji ogólnej pomieszczenia – ***dr inż. Barbara Lipska*** 33

WYDARZENIA

Ryszard Kaczorowski – ostatni Prezydent RP na Uchodźstwie w Naczelnej Organizacji Technicznej 40

Nagrody LAUR CIEPŁOWNICTWA w 2006 roku przyznane . . . . . II okł.

FELIETON TECHNICZNY

Młode talenty – ***Jerzy Kosieradzki*** . . . . . III okł

CONTENTS

Cooperation of Associated Systems Supplying Heat Engineering Plants Containing Renewable Electric Energy Sources – *Krzysztof Wojdyga, Małgorzata Kwestarz*, **page 3**

The problems connected with the balancing of the electric energy in wind power plants are presented. The paper takes into account spread associated systems generating the heat and electricity provided for supplying the heat engineering plants. The problem is still nonexistent in the Polish market because of the technological aspects of heat and electric energy generation. However, it is a matter of interest in such countries as Germany, Denmark or Spain. The detailed technical and economic analysis is included in the DESIRE 6 Project of the UE General Program. The paper was published among other conference materials at the X Forum Ciepłowników, Międzyzdroje 2006.

Investigation of Leak Tightness and Water Losses in Heat Engineering Plants – *Maciej Chorzelski, Krzysztof Wojdyga*, **page 11**

The main problems connected with water leakage and its detection in heat engineering plants have been analysed. The causes and points of maximal leakage of municipal water have been determined on the basis of examinations and analytical considerations. The data enables rational activities aiming for the reduction of water losses. The comparisons between various solutions of the system, existing in the country, have been shown. The results of the research works in various systems of heat engineering are included.

Power Energy and Exergy Effects of Low Exergy Heating Systems in Buildings – Part II: Advantages and Limitations of Low Exergy Systems – *Henryk Foit*, **page 16**

The discussion concerning the advantages and limitations resulting from the application of individual elements of heating systems is presented. Possible Installation of the mechanical ventilation is included.

Realisation of 2002/91/EC Directive Concerning Energy Characteristic of Buildings Taking Białystok as an Example – *Cezary A. Pieńkowski*, **page 20**

The effects of complex thermal modernisation of buildings are presented. The modernisation concerned multifamily buildings with total capacity of 17 635 170 m^3, and located in Białystok. The building administrators are eleven housing co-operatives, the Public Building Company and the Municipal Property Management. The activity of the administrators is consistent with the EC Directives

Influence of Various Factors on Expansion of Gas Pollution in Generally Ventilated Rooms – *Barbara Lipska*, **page 33**

The influence of various factors on the expansion of gas pollution in generally ventilated rooms has been analysed on the basis of examinations, by using the numeric method (Computational Fluids Dynamics). A practical application, useful in the design of air distribution in ventilated rooms, has been shown.

Climatic Data for Power Energy Calculations in Building Industry – *Piotr Narowski*, **page 22**

Flow Characteristics of Right-angle Bends with Square Cross Section – Part II: Numerical Computation – *Michał Szymański, Agata Latusek, Janusz Wojtkowiak*, **page 29**

A computer-based fluid dynamics examination method (CFD) has been applied to determine flow characteristics $K = f(R/D, Re)$ of a sharp-edged elbow and four bends with radian uses $R/D = 0{,}75$, 1, 2 and 3. All elements (used in automotive ventilation and air-conditioning systems) had square cross sections. The computations were carried out in the laminar and turbulent flow range. A satisfactory agreement with the experimental results (presented in the first part of the paper COW 10/2006) was found. The positive result of the CFD code validation enabled its application for an extended range of experimental characteristics beyond the lower ($Re < 2500$) and larger ($Re > 3{,}7 \times 10^4$) Reynolds numbers.

Tłumaczył: **mgr inż. Zbigniew Tymowski**

Współpraca układów skojarzonych zasilających systemy ciepłownicze z odnawialnymi źródłami energii elektrycznej

Dr inż. KRZYSZTOF WOJDYGA
Mgr inż. MAŁGORZATA KWESTARZ
Instytut Ogrzewnictwa i Wentylacji Politechniki Warszawskiej

Przedstawiono zagadnienia związane z bilansowaniem produkcji energii elektrycznej w elektrowniach wiatrowych poprzez rozsiane układy skojarzonego wytwarzania ciepła i energii elektrycznej zasilające systemy ciepłownicze. Problem ten z uwagi na technologię produkcji energii elektrycznej i ciepła nie istnieje na rynku polskim, ale jest jednym z podstawowych zagadnień na rynku niemieckim, duńskim czy hiszpańskim. Szczegółowa analiza techniczno-ekonomiczna jest przedmiotem projektu DESIRE 6 Programu Ramowego UE.

Referat został zamieszczony w materiałach konferencyjnych X Forum Ciepłowników, Międzyzdroje 2006.

INTEGRACJA odnawialnych źródeł energii na zliberalizowanym rynku energii elektrycznej jest wyzwaniem zarówno dla producentów, jak i odbiorców. Teraz bilansowanie energii w Europie powodowane zmieniającym się jej zużyciem, a szczególnie różnicami w prognozach pomiędzy produkcją a zużyciem. Obecnie całkowite zużycie energii elektrycznej jest zdecydowanie wyższe niż produkcja energii elektrycznej w farmach wiatrowych, ale w niektórych regionach, takich jak Północne Niemcy, Zachodnia Dania, a również częściowo w Hiszpanii produkcja energii elektrycznej z wiatraków jest znacząca w stosunku do całej produkcji, a niekiedy w ciągu roku energia elektryczna produkowana w tych źródłach jest dominująca. Niemniej ciągle jeszcze wydaje się, że energia elektryczna z wiatraków odgrywa małą rolę na rynku energii, ale na rynku bilansującym ten rodzaj energii odgrywa bardziej znaczącą rolę.

Obecnie do bilansowania wahań w produkcji energii elektrycznej z odnawialnych źródeł energii używane są wielkie klasyczne elektrownie (węglowe i jądrowe o dużych mocach), których głównym zadaniem jest praca w podstawie systemu elektroenergetycznego. Lepsze efekty regulacyjne będzie można osiągnąć, jeżeli w celu bilansowania produkcji energii elektrycznej używane będą układy elektrociepłowni i elektrowni wiatrowych tzw. kombinowane, które będą oferować korzystniejsze warunki na tę usługę na rynku energii, niż te oferowane przez wielkie elektrownie.

Kombinowane układy pozwolą na częściowe zbilansowanie fluktuacji w produkcji energii elektrycznej z elektrowni wiatrowych. Dzięki temu większość elektrowni wiatrowych używanych lokalnie nie będzie wpływać negatywnie na system elektroenergetyczny, ale będzie przeciwdziałać przeciążeniu i niedociążeniu sieci elektrycznej. Należy zauważyć, że małe źródła energii elektrycznej mogą zaspokajać lokalne potrzeby, które do tej pory zasilane były z dużych elektrowni. Dlatego też, małe źródła energii elektrycznej mogą zwiększyć konkurencyjność dostarczanej energii, pozwoli to również na podwyższenie jakości energii elektrycznej i stabilności pracy systemu elektroenergetycznego. Układy kombinowane elektrociepłowni i elektrowni wiatrowych stwarzają bardziej atrakcyjne i efektywniejsze finansowo warunki zasilania w energię elektryczną na wszystkich rynkach energii elektrycznej. Spowodować to może, że układy te staną się jeszcze bardziej konkurencyjne na rynku energii elektrycznej Unii Europejskiej. Powinno to również wpłynąć na obniżenie cen dla odbiorców i znaczną poprawę jakości zasilania w energię elektryczną.

Systemy elektrociepłowni współpracujące z elektrowniami wiatrowymi w produkcji i bilansowaniu energii są bardziej przewidywalne, mogą zasilać odbiorców w energię elektryczną i ciepło. Układy takie muszą być powiększone o dodatkowe urządzenia, które pozwolą na magazynowanie ciepła albo urządzenia pozwalające na wykorzystanie energii elektrycznej, która w danym okresie jest produkowana w nadmiarze.

W przypadku nadmiernej produkcji energii elektrycznej z elektrowni wiatrowych, elektrociepłownia zmniejsza produkcję energii elektrycznej, a jednocześnie zaspokaja zapotrzebowanie na ciepło mieszkańców i dodatkowo doładowuje zasobnik ciepła. Jeżeli wystąpi konieczność wyłączenia produkcji energii elektrycznej przez elektrociepłownię, odbiorcy ciepła zasilani będą z zasobnika ciepła. Kiedy produkcja energii z elektrowni wiatrowych jest nadmierna, a elektrociepłownia już nie produkuje prądu, „wiatrowa" energia elektryczna będzie zamieniana przez pompę ciepła w ciepło i będzie zasilała lokalnych odbiorców lub alternatywnie będzie doładowywała zasobniki ciepła, aby mieć zapas na pokrycie przyszłego przewidywanego zapotrzebowania. W sytuacji gdy produkcja energii elektrycznej z elektrowni wiatrowych jest niska, elektrociepłownie operują w kierunku dostarczania ciepła z akumulatorów i pokrywają braki w zasilaniu w energię elektryczną spowodowaną zatrzymaniem się elektrowni wiatrowych. Taki model współpracy źródeł energii prowadzony jest w duńskim systemie elektroenergetycznym. Duńskie układy produkcji skojarzonej zaprojektowane jako duża liczba małych wysokosprawnych źródeł, z dużymi zasobnikami ciepła, są optymalnym rozwiązaniem nie tylko do bilansowania zużycia energii elektrycznej, a również do optymalizacji pracy źródła ciepła.

Zasobniki ciepła mogą zmagazynować ciepło na około 6-godzinne pokrycie szczytowego zapotrzebowania. Takie przerwy w pracy źródła skojarzonego występują w wypadku produkcji energii elektrycznej uwzględniającej duńską taryfę potrójną, umożliwiają również bilansowanie fluktuacji energii z wiatru uczestnikom rynku energii dnia następnego.

Także w tym celu przy zupełnie innych wymaganiach zasobniki ciepła zwiększają współczynnik skojarzenia.

Zasobniki ciepła o mniejszej pojemności (np. 1 godzina) zapewniają większą elastyczność pracy źródła, a zasobniki o bardzo dużych pojemnościach zwiększają w sposób znaczący bezpieczeństwo dostawy ciepła. Chociaż układy z zasobnikami są bardzo użyteczne, to jednak problemy produkcji skojarzonej występują w okresie letnim, gdyż zmienne w czasie i na dużo niższym poziomie zapotrzebowanie na ciepło wpływa na zmniejszenie produkcji energii elektrycznej.

Część ciepła może być wykorzystana efektywnie, np.: do chłodzenia przy użyciu absorpcyjnych pomp ciepła lub w ostateczności ciepło może być tracone. Bardziej efektywnym sposobem może być kombinacja z innymi technikami włączając w to hydroenergetykę. Ale najlepszym rozwiązaniem jest wykorzystanie techniki Demand Side Management (Zarządzanie Stroną Popytową) przy użyciu układów skojarzonych, ponieważ umożliwia to skuteczne absorbowanie energii elektrycznej produkowanej w najkorzystniejszych warunkach wiatrowych.

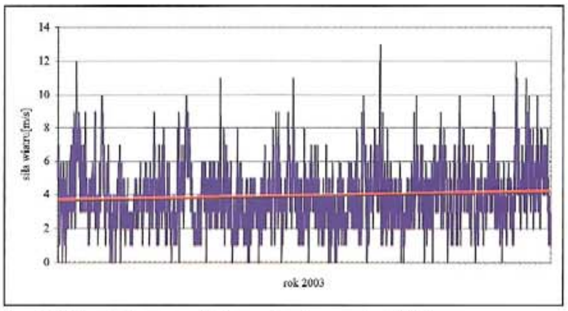
Produkcja energii elektrycznej w farmach wiatrowych

Produkcja energii elektrycznej ze źródeł odnawialnych, jakimi są wiatraki, w wielu krajach europejskich stanowi już znaczący udział w bilansie energetycznym tych krajów, a planowany dalszy rozwój tej technologii może doprowadzić to tego, że moce zainstalowane w farmach wiatrowych stanowić będą ponad 50% mocy całego systemu elektroenergetycznego. W Polsce sytuacja jest odmienna. Do końca 2004 roku pracowało ponad 50 wiatraków z łączną mocą zainstalowaną wynoszącą 63 MW. W roku 2005 nie przybyło ani jednego wiatraka. Dyrektywa 2003/54/EC z 26 czerwca 2003 roku dotycząca „wspólnych zasad na wewnętrznym rynku energii elektrycznej" zmieniająca Dyrektywę 96/92/EC oraz Dyrektywa 2001/77/EC dotycząca „promowania energii elektrycznej wyprodukowanej z odnawialnych źródeł energii na wewnętrznym rynku energii elektrycznej" nakłada na kraje członkowskie obowiązek corocznego zwiększania produkcji energii elektrycznej ze źródeł odnawialnych. I tak Polska zobowiązała się, że do roku 2010 udział takiej energii zwiększy się do 7,5%. Kolejne rozporządzenia ministra gospodarki dotyczące „szczegółowego zakresu obowiązku zakupu energii elektrycznej i ciepła z odnawialnych źródeł energii oraz energii elektrycznej wytwarzanej w skojarzeniu z wytwarzaniem ciepła", nie spowodowały nowych inwestycji i wzrostu produkcji energii elektrycznej z tych źródeł.

W wielu krajach prognozowany jest znaczny wzrost mocy zainstalowanej w farmach wiatrowych tak na lądzie, jak i na wodach morskich (off shore) (tabela 1).

TABELA 1. Moce zainstalowane w wiatrakach w krajach uczestnikach projektu DESIRE

Kraj	Moc zainstalowana, GW 2004 r.	Moc zainstalowana, GW 2020 r.
Estonia	0,007	0,58
Dania	2,2	2,5
Niemcy	16,6	54
Polska	0,06	1
Hiszpania	8,3	35
Wielka Brytania (Szkocja)	0,2	3



Rys. 1. Siła wiatru na polskim wybrzeżu w roku 2003

Przyjęta prognoza wzrostu mocy zainstalowanej w źródłach odnawialnych jest niezbyt optymistyczna, ale wydaje się realna. Inne prognozy nawiązujące do uchwalonej przez Sejm RP w roku 2001 *„Strategii rozwoju energetyki odnawialnej"* przyjmują znacznie większy wzrost w kolejnych latach. I tak przyjęto, że w roku 2005 zainstalowana moc wyniesie 450 MW, co nie zostało wypełnione. Na rok 2010 przyjęto 1100 MW, na rok 2020 przyjęto wzrost do 3000 MW, a na rok 2030 – 5000 MW. Zgodnie z najnowszymi informacjami w czerwcu 2006 roku uruchomione zostały dwie farmy wiatrowe w Gnieżdżewicach o mocy 22 MW i w Tymieniu o mocy 50 MW. Daje to łącznie (z dotychczasowymi) 135 MW, czyli w stosunku do roku 2004 jest to podwojenie mocy zainstalowanej. Zgodnie z danymi Polskich Sieci Elektroenergetycznych wydane zostały warunki techniczne do budowy nowych źródeł o łącznej mocy prawie 1700 MW. Jeżeli nie zmienią się uwarunkowania ekonomiczne przedstawione cele zwiększenia mocy zainstalowanej nie zostaną wypełnione.

Zasoby energetyczne wiatru są bardzo korzystne, są one jednak na tyle atrakcyjne, że mogą stać się znaczącym uzupełnieniem energetyki konwencjonalnej opartej na węglu. Bardzo korzystne warunki wiatrowe panują na wybrzeżu morskim, na krańcach Polski północno-wschodniej oraz przełęczach górskich w Karpatach i Sudetach. Na pozostałych obszarach warunki wiatrowe są zdecydowanie gorsze. Ekonomicznie uzasadniona jest praca wiatraków przez okres co najmniej 6000 godzin w roku, przy prędkości wiatru nie mniejszej niż 6 m/s na wysokości 40 m ponad poziomem gruntu. Na rysunku 1 przedstawiono rozkład prędkości wiatru we wschodniej części polskiego wybrzeża. Linia pozioma pokazuje średnią wartość siły wiatru w roku 2003. Jest ona na poziomie 4 m/s.

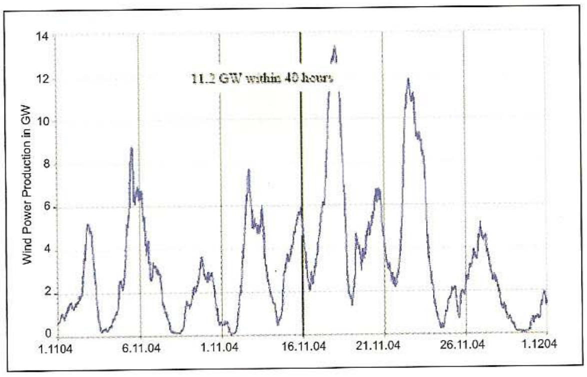
Dwa najważniejsze aspekty uzyskiwania energii elektrycznej z wiatru, które muszą być uwzględnione w rozważaniach, to fluktuacje w produkcji zależne od warunków meteorologicznych oraz koncentracja mocy źródeł energii wiatrowej na danym obszarze przy średnich, typowych warunkach wietrzności. Oczywiście najlepsze warunki wietrzności nie występują w regionach o największym zużyciu energii elektrycznej. W takim wypadku konieczne jest przesyłanie energii odnawialnej na dalsze odległości. W Niemczech występuje taka konieczność przesyłania energii elektrycznej z północy do odbiorców w południowej i zachodniej części Niemiec. Z tego powodu sieć elektroenergetyczna wysokiego napięcia jest przeciążona i będzie przeciążona w najbliższej przyszłości (DENA 2005).

Bilansowanie produkcji energii elektrycznej z jej zmiennym zużyciem jest konieczne, jeżeli uwzględni się zmienność warunków pogodowych, od których zależy prędkość wiatru, a w trzeciej potędze od siły wiatru zależy generowana moc elektryczna. Na rysunku 2 przedstawiono fluktuacje w mocy elektrycznej z farm wiatrowych w Niemczech w listopadzie 2004 roku.

Jak widać z tego rysunku zmiany w wielkości produkcji są znaczące. Wykres składa się z 9 okresów podwyższonej produkcji. Przy średniorocznej mocy w wysokości 2,7 GW najwyższa produkcja w szczycie jest 4 razy większa od średniej, a najmniejsza generowana moc osiąga tylko 2% wartości średniej. Takie odchylenia muszą być zbilansowane w krótkim czasie. Jest możliwych kilka rozwiązań technicznych problemu bilansowania energii elektrycznej związanej ze zmianami warunków wietrzności na danym obszarze:

• **prognoza wietrzności.** Porównywanie zmian w zużyciu energii elektrycznej ze zmianami wynikającymi z prognoz warunków meteorologicznych związanych z wiatrem. Planowany zapas mocy w konwencjonalnych elektrowniach powinien uwzględniać prognozowaną produkcję energii ze źródeł odnawialnych. Do prognozowania produkcji energii elektrycznej w farmach wiatrowych służą programy komputerowe opracowane przez różne firmy. Dokładność prognozowania na 1 dzień wynosi około 9%, dokładność prognozy zwiększa się dla krótszego okresu prognozowania, np. 6 godzin (ISETB 2004),

• **hydroenergetyka.** W państwach takich jak Norwegia, Szwajcaria, Austria, Hiszpania i Niemcy elektrownie wodne ze zbiornikami retencyjnymi mogą być dobrym rozwiązaniem bilansowania produkcji i zużycia energii elektrycznej. Układ taki w bardzo krótkim okresie, ok. minuty, może być włączony lub wyłączony z pracy. Ponadto w okresach nadprodukcji energii elektrycznej, może być ona ze sprawnością ok. 70% magazynowana w zbiornikach wodnych,



Rys. 2. Fluktuacje w produkcji energii elektrycznej w Niemczech w listopadzie roku 2004 w farmach wiatrowych

• **powiększenie obszaru zasilania.** Innym sposobem bilansowania fluktuacji produkcji energii elektrycznej z farm wiatrowych jest powiększenie obszarów zasilania, czyli przesyłanie energii na dalsze odległości. Powiększony obszar zasilania nie potrzebuje dużych możliwości regulacyjnych, ponieważ szczyty zapotrzebowania na energię elektryczną, jak i szczytowa produkcja występują w różnych porach doby,

• **zarządzanie strona popytową (DSM).** Bardziej interesującym sposobem bilansowania jest spowodowanie zmiany zachowań odbiorców tak, aby zwiększone zużycie energii elektrycznej występowało w szczytach produkcji ze źródeł odnawialnych. Szczególnie takie zachowanie mogłoby być korzystne dla odbiorców przemysłowych, jak i indywidualnych korzystających z pomp ciepła, ogrzewania elektrycznego itp.,

• **ciepłownia z układem skojarzonym i dużym zasobnikiem ciepła.** Kolejną możliwością jest wykorzystaniem ciepłowni z układem skojarzonym. Zaletą układu skojarzonego jest wyższa sprawność całkowita w porównaniu do rozdzielonej generacji energii elektrycznej i ciepła. Produkcja ciepła w ilości odpowiadającej w pierwszej kolejności pokryciu zapotrzebowania na ciepło może nie być dobrym sposobem bilansowania fluktuacji produkcji energii z wiatraków. Jeżeli jednak w układzie wykorzystany zostanie duży zasobnik ciepła, to w sposób elastyczny może bilansować fluktuacje energii wiatrowej. Ważnym pytaniem jest jaka powinna być wielkość zasobnika, aby zaspokoić różne profile zapotrzebowania na ciepło u odbiorców.

Układy skojarzonej produkcji ciepła i energii elektrycznej

Poniżej przedstawiono uwarunkowania możliwości wykorzystania małych elektrociepłowni do bilansowania fluktuacji energii elektrycznej produkowanej w farmach wiatrowych. Interesującym pytaniem jest to, jak bilansować energię elektryczną obecnie, a jak w niedalekiej przyszłości. Korzystając z doświadczeń innych krajów rozwój energetyki odnawialnej opartej na farmach wiatrowych powinien być ściśle skorelowany z budową lokalnych źródeł skojarzonych.

Skojarzone układy produkujące ciepło i energię elektryczną są rozwiązaniem bardziej efektywnym niż produkcja rozdzielona w elektrowniach i ciepłowniach. Taka skojarzona produkcja pokrywa zapotrzebowanie na ciepło i energię elektryczną, może się to odbywać w sposób ekonomicznie uzasadniony. Z technicznego, jak również z ekonomicznego punktu widzenia, energia elektryczna jest bardziej wartościowa niż ciepło. Dlatego też produkcja energii elektrycznej w elektrociepłowni wpływa w sposób istotny na sytuację ekonomiczną zakładu.

Produkcja i zużycie energii elektrycznej odbywa się z wykorzystaniem sieci elektroenergetycznej. Daje to trzy możliwe podejścia:

a) pokrycia własnych potrzeb; jest to typowe rozwiązanie dla przemysłu i dla małych odbiorców, którzy w ten sposób redukują koszty dostawy energii,

b) dostawa energii elektrycznej do sieci publicznej po cenach zgodnych z taryfami za energię elektryczna,

c) dostawa dla Operatora Systemu Dystrybucyjnego, który zasila odbiorców i jednocześnie integruje pracę elektrociepłowni i jest odpowiedzialny za bilansowanie energii elektrycznej oraz odchyleń między prognozowanym a aktualnym zapotrzebowaniem systemu dystrybucyjnego.

Wyróżnia się dwa ogólne przypadki taryf za energię elektryczną: taryfę stałą i taryfę zmienną. W taryfie stałej koszty produkcji nie są związane z zapotrzebowaniem na energię.

Dla taryfy zmiennej istotne są kolejne trzy przypadki:

– najprostszym przypadkiem zmiennej taryfy jest taryfa w dwóch wysokościach: wysoka cena za energię, przy wysokim zapotrzebowaniu i niska w pozostałym okresie. Mogą być również różnice w okresie letnim i zimowym,

– w Danii stosowana jest taryfa potrójna, w której uwzględniono dodatkowo szczytowe zapotrzebowanie na energię, przy którym cena za energię jest znacząco wyższa,

– rynek dnia następnego zakłada różną cenę za energię dla każdej godziny w roku.

Produkcja ciepła jest ściśle związana z profilem zapotrzebowania na ciepło. W układzie skojarzonej produkcji ciepła i energii elektrycznej możliwości regulacyjne zależą od produkcji i sprzedaży energii elektrycznej. Na warunki produkcji ciepła i energii elektrycznej mają wpływ następujące parametry przedstawione i opisane poniżej:

• roczne zapotrzebowanie na ciepło,

- różne rodzaje profili zapotrzebowania na ciepło,
- wielkość elektrociepłowni,
- pojemność zasobnika ciepła,
- współczynnik skojarzenia dla ciepła.

Roczne zapotrzebowanie na ciepło

Typowe jednostki kogeneracyjne w postaci silników produkują ciepło i energię elektryczną w stosunku 1:1 (45/45 dla dużych silników Diesla) oraz 2,4:1 (56/23 dla małych silników napędzanych gazem). To znaczy, że ilość produkowanego ciepła powinna być zbliżona lub znacząco wyższa niż ilość produkowanej energii elektrycznej. Stosunek całkowitego rocznego zapotrzebowanie na ciepło i energię elektryczną musi odpowiadać możliwościom produkcyjnym zainstalowanych jednostek, a profile zapotrzebowania na ciepło i energię elektryczną powinny zapewnić dobre warunki produkcji energii.

Profile zapotrzebowania na ciepło

Profil zapotrzebowania na ciepło może być prawie stały, w przypadku odbiorców przemysłowych, w przeciwieństwie do zmiennego profilu zapotrzebowania na ciepło na cele grzewcze, które głównie zależą od temperatury zewnętrznej.

TABELA 2. Rynki energii w trzech krajach

Kraj	Rynek podstawowy
Dania	Nordpool taryfa potrójna
Niemcy	EEX Rynek zielonej energii
Wielka Brytania	Szczyt/dolina oraz zima/lato

Współczynnik skojarzenia dla ciepła

Współczynnik skojarzenia potrzeb cieplnych jest to roczny stosunek ciepła wyprodukowanego w skojarzeniu do całkowitej ilości wyprodukowanego ciepła. Pozostałe zapotrzebowanie na ciepło pokrywane jest z kotłów szczytowych. W efekcie daje to wyższą sprawność i mniejsze zużycie paliwa. Ciepło w skojarzeniu powinno być produkowane w jak największej ilości, gdyż współczynnik skojarzenia wpływa na wzrost sprawności.

Wielkość elektrociepłowni

Wielkość elektrociepłowni określona jest: możliwością pokrycia szczytowego zapotrzebowania na energię oraz ilością godzin pracy z maksymalną wydajnością w zależności od rocznych potrzeb energetycznych w powiązaniu ze współczynnikiem skojarzenia i zapotrzebowaniem na ciepło.

Pojemność zasobnika ciepła

Zasobnik gorącej wody jest ładowany w czasie, kiedy jednostki w elektrociepłowni produkują więcej ciepła niż wymagają aktualne potrzeby. I odwrotnie, kiedy jednostki elektrociepłowni nie pracują lub pracują z wydajnością mniejszą niż zapotrzebowanie na ciepło, to zasobnik jest rozładowywany i ciepło dostarczane jest do odbiorców z zasobnika. Bez zasobnika ciepła kotły ciepłownicze pracują zarówno w czasie dużego zapotrzebowania na ciepło, jak i zapotrzebowania małego. Również wielkość zasobnika wpływa na współczynnik skojarzenia ciepła, a szczególnie na pokrycie szczytowego zapotrzebowania na ciepło.

Jeżeli układ skojarzony ma bilansować fluktuacje w produkcji energii elektrycznej z farm wiatrowych, może się to odbywać zgodnie z dwiema możliwymi opcjami: techniczną i rynkową. W opcji technicznej, elektrociepłownia i turbiny wiatrowe są bilansowane, uwzględniając zapotrzebowanie na energię elektryczną. Używając opcji rynkowej, elektrociepłownia sprzedaje energię elektryczną na jednym lub wielu rynkach energii.

Ceny obowiązujące na tych rynkach bardzo często zależą od zmieniającej się produkcji energii elektrycznej z turbin wiatrowych. W rozważaniach, w jaki sposób dostosować istniejące elektrociepłownie lub budować nowe układy skojarzone opierając się na opcji rynkowej, należy kierować się następującymi przesłankami:

– przede wszystkim dobrze poznać i opisać rynek energii, na którym sprzedawana będzie energia,

– określić należy średnie ceny rynkowe w ciągu całego roku,

– obliczyć przychody ze sprzedaży z uwzględnieniem pracy elektrociepłowni w różnych warunkach również z lub bez zasobników ciepła. Wykorzystać do tego celu można program symulacyjny energyPRO,

– obliczyć przychody na rynkach wtórnych uwzględniając, że silniki kogeneracyjne w miesiącach letnich będą stanowić rezerwę (mogą, jeżeli to będzie konieczne korzystać z chłodni kominowych).

W zależności od rodzaju rynku energii i warunków tam panujących, wyniki analiz ekonomicznych mogą być różne. W projekcie DESIRE analizy ekonomiczne przeprowadzone zostaną dla rynków energii w trzech krajach: Danii, Niemczech i Wielkiej Brytanii (tab. 2).

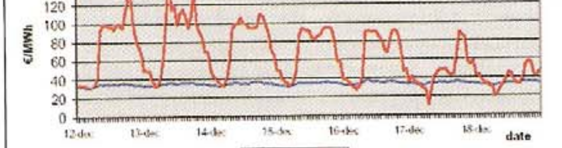
Jest oczywiste, że znajomość reguł na podstawowych rynkach energii jest niezbędna do wykonania analiz ekonomicznych i przyszłych wpływów z produkcji ciepła oraz energii elektrycznej. Nie jest to proste zadanie. Wiele różnych warunków musi być uwzględnione. Inwestycje w elektrociepłownie zasilające systemy ciepłownicze są inwestycjami, które amortyzować się będą przez wiele następnych lat. W tym też czasie będą produkowały energię elektryczną i ciepło. A zatem trzeba zadać pytanie:

- Czy rynek, jaki widzimy obecnie, będzie podobny do rynku w przyszłym roku lub za następne 10 lat?
- O ile więcej będzie na rynku energii elektrycznej ze źródeł o znacznej fluktuacji produkcji?

Systemy rynkowe są stosunkowo nowe i nie wiadomo jak się będą przekształcały, a struktura systemów elektroenergetycznych poddawana jest ciągłym modernizacją.

Na rysunku 3 pokazano różnice w cenie energii elektrycznej w okresie od 12 do 18 grudnia 2005 roku na dwóch rynkach, rynku niemieckim EEX i na rynku skandynawskim NordPool.

Różnice między tymi dwiema taryfami są widoczne. Taryfa EEX jest zmienna o wiele bardziej niż taryfa NordPool, która od wielu tygodni utrzymuje się na stałym poziomie. Na tym wykresie nie jest to pokazane ale zarysowana tendencja jest jasna. Jest to oczywiste, że warunki ekonomiczne projektu nowej elektrociepłowni lub modernizacji istnie-



Rys. 3. Ceny energii elektrycznej na rynku Nordpool i EEX

jącej będą się znacznie różniły po uwzględnieniu warunków na rynku energii takim jaki jest rynek EEX lub NordPool ze swoimi cenami. W pierwszej kolejności powinny być realizowane projekty z wysoką zainstalowaną mocą elektryczną, z dużymi zasobnikami ciepła, które będą w stanie zapewnić produkcję energii elektrycznej w godzinach o jej najwyższej cenie.

Podsumowanie

Zużycie energii elektrycznej w Polsce jest na niezbyt wysokim poziomie. Średnie zużycie na mieszkańca wynosi około 3800 kWh/osobę w ciągu roku. Podniesienie poziomu życia mieszkańców wiąże się w sposób bezpośredni ze zwiększeniem zużycia energii elektrycznej. Obecnie moce zainstalowane w źródłach energii elektrycznej są wystarczające do zaspokojenia potrzeb odbiorców. W przypadku corocznego wzrostu zużycia energii elektrycznej o około $2 \div 3\%$ do roku 2015 może się okazać, że moce zainstalowane w polskim systemie elektroenergetycznym są niewystarczające do pokrycia potrzeb odbiorców. Szczególnie, że znacząca część elektrowni pracuje z niską sprawnością (30-33%) i powinna być w najbliższym okresie zmodernizowana. Wymagana będzie również budowa nowych źródeł. Możliwe są dwa warianty scenariusza: budowa dużych wysokosprawnych źródeł scentralizowanych, w tym elektrowni jądrowych lub budowa dużej liczby małych rozproszonych źródeł energii elektrycznej.

Zgodnie ze strategią [4] możliwości budowy skojarzonych źródeł uwzględniając Dyrektywę 2004/8/EC oszacowano na 3000 MW. Uzupełnieniem układów skojarzonych małych mocy powinna być budowa farm wiatrowych produkujących energię elektryczną o mocy 1-2 GW do roku 2020. Przy planowaniu budowy farm wiatrowych w bliskiej okolicy, w miastach powinny powstawać małe układy skojarzone produkujące ciepło na potrzeby miejskich systemów ciepłowniczych, a energia elektryczna powinna być produkowana przez możliwie najdłuższy czas.

Niniejszy artykuł powstał na podstawie materiałów roboczych projektu DESIRE, który jest realizowany w 6. Ramowym Programie finansowanym przez Unię Europejską. Politechnika Warszawska jest jednym z uczestników tego projektu. DESIRE ma za zadanie określenie możliwości współpracy odnawialnych źródeł energii elektrycznej, jakimi są elektrownie wiatrowe ze źródłami skojarzonej produkcji energii elektrycznej i ciepła (CHP) w systemie elektroenergetycznym.

LITERATURA

[1] Dyrektywa 2003/54/EC z 26 czerwca 2003 roku dotyczącej „wspólnych zasad na wewnętrznym rynku energii elektrycznej zmieniająca dyrektywę 96/92/EC
[2] Dyrektywa 2001/77/EC dotyczącej „promowania energii elektrycznej wyprodukowanej z odnawialnych źródeł energii na wewnętrznym rynku energii elektrycznej"
[3] Dyrektywa 2004/8/EC „w sprawie promowania kogeneracji w oparciu o zapotrzebowanie na ciepło użytkowe na wewnętrznym rynku energii oraz wnosząca poprawki do Dyrektywy 92/42/EEC"
[4] Strategia rozwoju skojarzonego wytwarzania energii elektrycznej i ciepła oraz ciepłownictwa. Uczelniane Centrum Badawcze Eneretyki i Ochrony Środowiska, Politechnika Warszawska, Warszawa, luty 2005
[5] DESIRE WP-2 „Concepts for small scale CHP units to be integrated into buildings or industry and medium scale CHP units with district heating" John Sievers, Ingo Stadler, Jurgen Schmid, University of Kassel, Kassel May 2006

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Heki Tammoja, Professor, Head of the Department of Electrical Power Engineering, Tallinn University of Technology
E-mail	heiki.tammoja@ttu-ee
Title of dissemination	Qua vadis, Heat and Power Co-generation in Estonia
Type of activity	Paper in local journal of electrical technology
Title of forum	"Elektriala" (Electricity field), 8 (2006) Nr. 4, pp. 16-17, (In Estonian)
Language	Estonian
Date of dissemination	September 20th 2006
Place of dissemination	Tallinn, Estonia
Brief abstract / description of dissemination activity	The paper gives a review of the seminar titled "Qua vadis, heat and power cogeneration in Estonia, organised by the Ministry of Economic Affairs and Communication, power company Estonian Energy and Tallinn University of Technology on 2. August in ´the new building of Power Engineering faculty of TUT. . Economic and technical problems of CHP development, dispersed generation and existing plans of CHP plant projects were considered at the seminar. The role of DESIRE project for broader application of wind turbines was especially outlined as well in seminar, so in the published overview.
Audience impact assessment	The main aim of the seminar and so of the paper was the development of CHP process itself and not specially the CHP with energy stores. Therefore the attempts to rise the importance of using energy stores with CHP didn't find much support, especially considering the lack of supporting legislation
Dissemination	Included after this form

Heiki Tammoja
Tehnikakandidaat,
Tallinna Tehnikaülikooli
elektroenergeetika
instituudi professor

Quo vadis, soojuse ja elektri koostootmine Eestis?

Majandus- ja Kommunikatsiooniministeerium, Eesti Energia AS ja Tallinna Tehnikaülikool korraldasid 2. augustil TTÜ energeetikamajas seminari "Quo vadis, soojuse ja elektri koostootmine Eestis. Osavõtjaid oli üle 100.

Kohaletulnuid tervitas ja seminari avas moderaator, Majandus- ja Kommunikatsiooniministeeriumi energeetikaosakonna juhataja **Einari Kisel**, kes oma sissejuhatavas sõnavõtus nimetas seminari kokkukutsumise peapõhjustena soojuse ja elektri koostootmise ja taastuvate energiaallikate toetusskeemide tutvustamist elektrituruseaduse eelnõus, tõhusa koostootmise (Euroopa Liidu mõistes) kriteeriumite tutvustamist ja soojuse ja elektri koostootmise perspektiive ja koostootmise võimalikke tehnoloogiaid Eestis.

Avaettekande tegi **Einari Kisel**, kes tutvustas koostootmise ja taastuva energia toetusskeeme "Elektrituruseaduse" muutmise eelnõus ja soojusturu arengut põlevkiviõli ja maagaasi hinna tõusu tingimustes. Eestis toodetakse koostootmisjaamades praegu 12–13 % elektrit Eesti brutotarbimisest. Aastaks 2020 peaks elektri ja soojuse koostootmisjaamades toodetud elektri osakaal Eesti brutotarbimisest moodustama 20 %. Taastuvenergiast toodetud elektri osakaal brutotarbimisest peaks 2010 aastaks olema 5,1 % ja aastaks 2015 vähemalt 8 %.

Planeeritav uus taastuvelektri ja koostootmise regulatsioon kehtib järgmistele tootjatele: taastuvelektri tootmisel tootmisseadmetega võimsus alla 100 MW_e, tõhusa koostootmise talitlusel koostootmisjaamas, mis põletavad turvast või jäätmeid ja tõhusa koostootmise talitlusel koostootmisjaamas, mis rajatakse katlama asemele ja mille võimsus ei ületa 10 MW_e. Planeeritav uus taastuvallika elektritootmise ja koostootmise regulatsioon annab tootjatele kolm võimalust.

1. Taastuvatest energiaallikatest toodetud elektri müügiõigus (Eesti Energia AS Teenindus ostukohustus) hinnaga 81 senti/kWh. Elektrituulikute puhul kehtib see hind hetkeni, mil nende kogutoodang ületab 200 GWh.

Turba või jäätmete baasil või katlamaja asemel ehitatud koostootmisjaama puhul on müügiõigus hinnaga 47 senti/kWh – kehtib 12 aastat tegevuse alustamisest.

2. Taastuvatest energiaallikatest toodetud elektri müügil elektriturule turuhinnaga on ette nähtud täiendav toetus OÜ Põhivõrgult 50 senti/kWh.

Turba või jäätmete baasil või katlamaja asemel ehitatud koostootmisjaama puhul on elektri müügil turule turuhinnaga täiendav toetus OÜ Põhivõrgult 16 senti/kWh – kehtib 12 aastat alates tegevuse alustamisest.

Elektrituulikute puhul kehtib see hind hetkeni, mil nende kogutoodang ületab 400 GWh.

3. Elektri müük turule turuhinnaga, kuid kohustuslik on päritolutunnistus, st müüa "rohelist elektrit" või "koostootmiselektrit" staatustootena. Kehtivuspiiranguid ei ole.

Põlevkiviõli ja maagaasi hinnatõus tõstab ka oluliselt tarbijatele müüdava soojuse hinda. Põlevkiviõli puhul on võimalik rakendada klassikalist riigiabi, st toetatakse soojusettevõtteid, kes kasutavad põlevkiviõli kaugkütte soojuse tootmiseks. Riigiabi andmine eeldab Euroopa Komisjoni luba. Eestis soojuse tootmiseks kasutatavate kütuste struktuur on toodud **joonisel 1. E. Kisel** rõhutas oma ettekande lõpus, et uus planeeritav regulatsioon "Elektrituruseaduses" toetab uute tõhusate koostootmisjaamade rajamist Eestis.

Järgmise ettekande esitas *Tallinna Tehnikaülikooli elektroenergeetika instituudi* direktor **Heiki Tammoja** teemal ***Elektrienergia hajatootmine***. Ettekandja esitas elektrienergia hajatootmise põhitunnused: põhiliselt kohalike kütuste ja jäätmete kasutamine, elektrijaamade ühendamine jaotusvõrku, elektri tootmine põhiliselt kohalikule tarbijale jne. Hajatootmise eelisteks on: kohalike kütuste kasutamine, võrgukadude vähenemine ja elektrivarustuse talitluskindluse suurenemine. Hajatootmise põhilisteks puudusteks on: elektrisüsteemi operatiivjuhtimine muutub keerulisemaks, suureneb reservi vajadus ja süsteemi automaatika ning releekaitse muutub keerukamaks ja kallimaks. Ettekandja tutvustas mõningaid Euroopa Liidu programmides tehtavate

Kütuste kasutus sooja tootmiseks Eestis 2004

teadustööde tulemusi. Projektis DESIRE (Euroopa Liidu VI raamprogramm) vaadeldakse soojusakudega koostootmisjaamade ja elektrituulikute koostööd energiasüsteemis. Soojusakud võimaldavad oluliselt suurendada elektrituulikute kasumlikkust energiasüsteemis (elektrituulikute toodangu juhuslikkust saab siluda soojuse akumuleerimisega soojusakudes). Näiteks Taanis on kõik koostootmisjaamad varustatud soojusakudega.

Tallinna Tehnikaülikooli soojustehnika instituudi professor **Andres Siirde** andis oma ettekandes näpunäiteid, kuidas arvutada soojuse ja elektri koostootmise tulemusena saavutatavat kütusesäästu. Ettekandes vaadeldi põhiliselt Euroopa parlamendi ja nõukogu direktiivi 2004/8/EC ja selle kohandamist Eestis. Direktiivi põhiliseks eesmärgiks on suurendada energia tootmise efektiivsust koostootmisel ja primaarenergia kokkuhoidu siseturul, arvestades iga riigi majanduslikke ja klimaatilisi iseärasusi. Direktiivis on olulisel kohal üldkasuteguri mõiste. Üldkasutegur on elektrienergia, mehaanilise energia ja kasulikult tarbitud soojusenergia aastatoodangu suhe selleks tarbitud ja koostootmiseks kasutatud kütuse energiaga. Elektri ja soojuse tõhus koostootmine peab rahuldama kahte nõuet:

1. Kombineeritud auru-gaasitsükliga seadme ja vasturõhuauruturbiiniga seadme üldkasutegur peab olema vähemalt 80 %. Ülejäänud koostootmisseadmete (vaheltvõttudega auruturbiin, gaasiturbiin, sisepõlemismootor, Stirling-mootor, kütuseelemendid jne) aastane üldkasutegur peab olema vähemalt 75 %.

2. Soojuse ja elektri koostootmine peab tagama vähemalt 10 % primaarenergia kokkuhoidu, võrreldes soojuse ja elektri eraldi tootmisega.

Koostootmisel tekkiva primaarenergia säästu arvutamisel tuleb arvestada elektri ja soojuse eraldi tootmise kasutegureid (viiteväärtusi). Eraldi elektritootmises on erinevatele kütuste viiteväärtused kooskõlastatud EL liikmesriikide poolt ja need on kohustuslikud. Põlevkivil on see 39 %, puitkütustel 34 % ja maagaasil 52,5 %. Näiteks ka mõned viiteväärtused soojuse eraldi tootmisel (aur/soe vesi): puitkütus 86 %, põlevkivi 86 % ja maagaas 90 %.Elektri ja soojuse eraldi tootmise viiteväärtusi võib korrigeerida vastavalt jaama liitumispunkti pingele, aasta keskmisele välisõhutemperatuurile jne.

Raimo Pirksaar *Eesti Energia AS*st tutvustas Eesti Energia plaane osalemisel uute koostootmisjaamade ehitamisel. Eesti Energial on plaan osaleda järgmiste koostootmisjaamade projektides: Kuressaare, Pärnu, Tartu, Tallinna prügipõletus, Viiratsi biogaas ja Ahtme koostootmisjaam. Esineja tõi välja viis olulist eeldust koostootmisjaama rajamisel:

- Soojuse tarbijate olemasolu.
- Kodumajapidamiste korral kaugküttevõrk.
- Elektrivõrgu olemasolu (pingega 10 kV või kõrgem).
- Koostöö kohaliku omavalitsusega.
- Koostöö kaugküttevõrgu operaatoriga.

Järgmise pikema ettekande tegi **Eimar Jõgisu** (*ÅF-Estivo AS*). Ettekande teemaks oli "Eesti erinevate piirkondade eeluuring koostootmisjaamade ehitamiseks". Ettekandja tegi ülevaate koostootmisjaamades kasutatavatest tehnoloogiatest. Põhiline tähelepanu oli suunatud taastuvenergiat kasutatavatele tehnoloogiatele. Tutvustati puidu otsese põletamise, gaasistamise ja tuleviku tehnoloogiaid. Kasutatavate tehnoloogiate struktuur on toodud **joonisel 2**. Orgaanilise soojuskandjaga (ORC) seade on Eestis suhteliselt vähetuntud tehnoloogia. ORC seadme põhimõtteline koostootmisjaama skeem on toodud **joonisel 3**. Ettekandja andis põhjaliku ülevaate tehnoloogiatest, nende kasutegurist , hindadest ja tootjatest. Kokkuvõtlikult põhitulemused:

1. Auruturbiiniga koostootmisjaam: maailmas levinuim ja töökindel tehnoloogia, sobib alates võimsusest 2 MW_e .

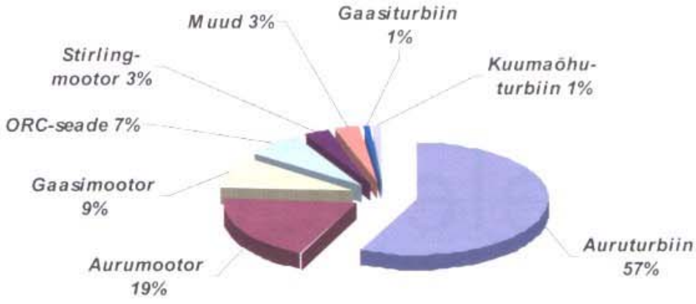
2. Aurumootoriga koostootmisjaam: vähe levinud, hoolduskulud suuremad kui auruturbiinil ja õlivabad aurumootorid on alles väljatöötamisel.

3. Orgaanilise soojuskandjaga tehnoloogiad: madalad hoolduskulud, orgaaniline vedelik pole korrodeeriv ja kulutab vähem turbiini, osalise koormusega töötamisel kõrgem kasutegur, hetkel kallim auruturbiiniga koostoomisjaamast, suhteliselt uus tehnoloogia ja arendustöö jätkub.

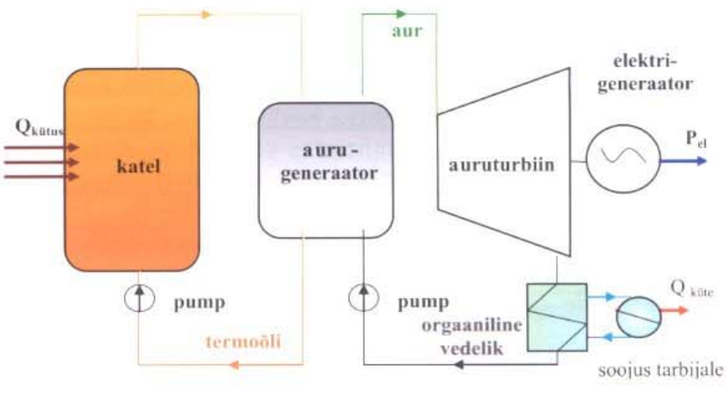
4. Gaasimootorid: kasutegur üle 85 %, suhteliselt madal hind, põhiliseks probleemiks on generaatorgaasi puhastamine.

Elva Linnavalitsese esindaja **Kalev Kepp** tutvustas Elva katlamajade renoveerimise kogemusi. Ettekandja rõhutas oma ettekande lõpus, et kaugkütte ja konkurentsivõimelise elukeskkonna säilitamiseks on vajalikud lisafinantseeringud ja lisafinantseeringute kaasrahastamiseks on vajalik infrastruktuuri kuulumine kohalikule omavalitsusele.

Seminar lõppes elava diskussiooniga.



Koostootmisjaamades kasutatavad seadmed



Orgaanilise soojuskandjaga koostootmise (ORC) tehnoloogiline skeem

SUMMARY

Juhan LAUGIS, Endel RISTHEIN
History of the development of the Institute of Electrical Drives and Power Electronics of the Tallinn University of Technology
Elektriala 8 (2006), No. 4, pp. 9–12 (in Estonian)
On 1956-09-01 the Chair of Industry Electrification, transformed into an Institute from 1992-06-09, was established. As result of the 50 years of its activities, 1758 electrical engineers have earned their diploma in this field. At present the staff of the Institute consists of 2 professors, 6 associate professors and lecturers, 8 researchers and 6 employees.

Jaanus EISKOP
Modern computer network; fiber optic cables vs twisted pair wiring
Elektriala 8 (2006), No. 4, pp. 14–15 (in Estonian)
Advantages and disadvantages of the fiber optic cables in comparison with traditional twisted pair wiring systems are discussed.

Heiki TAMMOJA
Quo vadis, combined heat and power generation in Estonia?
Elektriala 8 (2006), No. 4, pp. 16–18 (in Estonian)
A report on the conference of the same name held at Tallinn University of Technology on 2 August 2006. Problems of the contemporary state and future development of the combined heat and power stations in Estonian power system and in industrial enterprises were discussed.

Arles TAAL
Vacuum or sulphur hexafluoride circuit breakers?
Elektriala 8 (2006), No. 4, pp. 19–20 (in Estonian)
A comparison of two modern high voltage circuit breakers, including different processes of overvoltage generation by arc extinction in the circuit breaker.

Tõnis MÄGI
New measuring devices in Estonian Electrical Inspectorate
Elektriala 8 (2006), No. 4, p. 21 (in Estonian)
An overview on the new measuring devices and installations recently put into service in laboratory of the Electrotechnical Inspectorate, provided for evaluation of the electromagnetic compatibility of different electrical apparatus.

Raivo TEEMETS
Winning success thank cooperation
Elektriala 8 (2006), No. 4, pp. 22–23 (in Estonian)
An overview on the long-standing successful cooperation between Tallinn University of Technology and large electrical enterprise *AS Harju Elekter* in the field of research and development and also in practical training of students.

Summer Gathering Days of the EAEE and other enterprises
Elektriala 8 (2006), No. 4, pp. 24–25 (in Estonian)
A report on different Summer Days organized by Electrical Enterprise AIA, Electrical Services Plc and Distribution Network of Eesti Energia in August 2006.

Hundreds of leaders of energy enterprises of the world will assemble in Tallinn
Elektriala 8 (2006), No. 4, p. 26 (in Estonian)
An advance notice on the Executive Assembly of the World Energy Council provided to take place in Tallinn on 3–7 September 2006.

Arvo ULLA
Savings by disregarding of the requirements of standards are criminal
Elektriala 8 (2006), No. 4, pp. 26–27 (in Estonian)
A notice on the necessity to comply the requirements of the standards established to the wiring systems of buildings. Fires due to incorrect wirings are mentioned as result of disregarding of these requirements.

New books
Elektriala 8 (2006), No. 4, p. 29 (in Estonian)
An introduction of the book by Assoc. Professors Valery Vodovozov and Raik Jansikene entitled **Power electronic converters** (in English) and the book by Assoc. Prof. Rain Lahtmets entitled **Technology and drives** (in Estonian) both provided as textbooks for Tallinn University of Technology and technical schools.

Jari PYNNÖNEN
New trends in electrical design
Elektriala 8 (2006), No. 4, pp. 30–31 (in Estonian)
An overview on the modern computer-aided design of electrical installations, including the use of a new system entitled IFC.

ELEKTRIALA
ilmub üks kord kahe kuu jooksul (6 numbrit aastas). Aastatellimusi võtavad vastu kõik sidejaoskonnad ja ajakirja talitus (Laki 13, 12915 Tallinn, telefon 679 7971 või 679 7974, faks 679 7973, e-post elektriala@elektriala.ee). Aastatellimus maksab 170 krooni. Talitus vormistab ka *jätkutellimusi* soodushinnaga 160 krooni aastas. Mõlemal juhul lisandub käibemaks 5 %. Talitusest saab osta ka ajakirja üksiknumbreid hinnaga 33 krooni. Vähesel arvul on talituses saadaval eelmiste aastakäikude numbreid.

Talituse juhataja Rein Jauk

ELEKTRIALA
järgmine number ilmub oktoobri lõpus 2006.

Artiklite vastuvõtt lõpeb 02. oktoobril, reklaamkuulutuste ja -kirjutiste vastuvõtt 09. oktoobril.

Dissemination strategy on Electricity balancing

DESIRE

large Scale Integration of Renewable Energy

Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Heiki Tammoja, Olaf Terno, Tallinn University of Technology
E-mail	heiki.tammoja@ttu.ee, olaf.terno@ttu.ee
Title of dissemination	Cogeneration plants can compensate wind farm power imbalance
Type of activity	Article in local journal of electrical technology
Title of forum	Elektriala – "Electricity field" 8 (2006) Nr. 1, pp. 12-13
Language	Estonian
Date of dissemination	February 20, 2006
Place of dissemination	Tallinn, Estonia
Brief abstract / description of dissemination activity	The paper states the principle of using cogeneration plants with thermal storages for balancing the varying output of wind turbines. In the paper the Danish experiences with such control technologies are shown.The paper's main aime is to initiate a discussion of using thermal storeges at cogeneration plants. Till now thermal storages are not used at cogeneration plants in Estonia. Tthe paper ends up with a proposal to continue the DESIRE Project in Estonia with elaboration of long term plan for development of CHP plants wiith energy stores in Estonia, and for introduction of required changes in Estonian legislation (Amendments to the Elektricity Market Acty etc)
Audience impact assessment	After one year from publication of paper the reader's reaction could be assessed as very small. No one of authorities or officials has not reacted to this paper with some proposal to discuss the matter in more detailed.
Dissemination	Included after this form

Koostootmisjaamad tasakaalustama elektrituuliikuid?

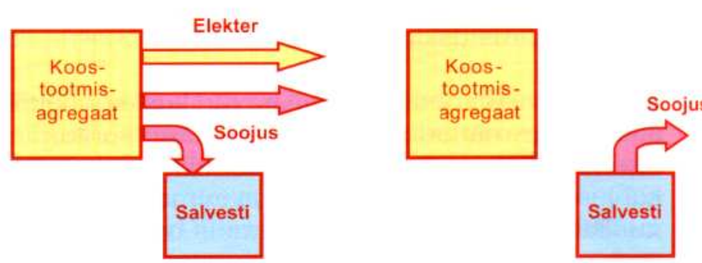
Heiki Tammoja
Professor,
Tallinna
Tehnikaülikooli
elektroenergeetika
instituudi direktor

Olaf Terno
Tehnikakandidaat,
Tallinna
Tehnikaülikooli
elektroenergeetika
instituudi
vanemteadur

Kõlab nagu veidi üllatavalt. Koostootmisjaamad töötavad teatavasti nõutava soojuskoormuse ehk praktiliselt välisõhu temperatuuri järgi ja igasugune reguleerimine tähendaks mängimist tarbijate soojavarustusega. Tuleb aga välja, et alati see nii ei pruugi olla. Näiteks juhul, kui koostootmisjaamal on suur soojussalvesti. Eestis neid tavaliselt ei ole, aga näiteks Taanis on nad kõigis koostootmisjaamades ja vägagi suured.

Soojussalvestite kasutamine hakkas Taanis levima 1989. aastal, kui koostootmisjaamadele kehtestati elektri eest maksmisel kolmeastmeline tariif. Nimelt viis senine üheastmeline tariif lõpuks olukorrani, kus Taani energiasüsteemi hakkasid ohustama tippkoormuse kiire kasv ja suurte riigipoolsete investeeringute vajadus selle katmiseks. Energeetika- ja majandusteadlased pakkusid Taani parlamendile arutamiseks probleemi koos lahendusega – haarata tippkoormuse katmisesse kõik koostootmisjaamad, makstes kõigile, kes toodavad nii soojust kui ka elektrit, tippkoormuse ajal toodetud elektrienergia eest sellist tasu, mis stimuleeriks energiatootjaid investeerima võimalustesse toota rohkem elektrienergiat ajal, mil seda kõige rohkem vaja on. Samal ajal hakkas tekkima ka vajadus midagi ette võtta **elektrituulikute** poolt toodetava võimsuse kõikumiste silumiseks. Eelkõige oli aga küsimus vahendite leidmises Taani elektrisüsteemi koormustippude katmiseks.

Küsimus anti arutamiseks Taani parlamendile, kes võttiski 1989. aastal vastu seaduse kolmeastmelise tariifi rakendamiseks koostoomisjaamade poolt toodetud elektrienergia eest tasumisel. Selle seaduse järgi makstakse tippkoormuse ajal, mis on kellaaegadel 08.00...12.00 ja 17.00...19.00, koostootmisjaamale 1 MWh eest 72 eurot (1112 eesti krooni), madala koormuse ajal aga 24 eurot (374 krooni). On veel vahepealne tariif 56 eurot, mis kehtib kell 06.00...21.00 väljaspool tippkoormuse aega. Kuna koostootmisjaamad kuuluvad Taanis põhiliselt kas soojustarbijate kooperatiividele, munitsipaalettevõtetele või kaugkütteteenust pakkuvatele firmadele, siis hakkasid need kõik oma kasumit maksimeerides elektrit tootma tippkoormuse ajal, tootes soojust nii tarbijatele kui ka soojussalvestitesse, ja kasutasid tipuvälistel aegadel tarbijate soojavarustuse tagamiseks salvestatud soojust (joonis 1). Ei ole eriti keeruline ülesanne etteantud maksetingimuste, teadaolevate kütusehindade, agregaatide ja salvestite parameetrite ja muude kulunäitajate järgi välja töötada jaama selline ööpäevane talitlusviis ja soojussalvesti selline mahtuvus, mis tagab suurima kasumi. Optimeerimisvariante võib olla mitmeid.



Joonis 1. Koostootmisjaama soojussalvesti kasutamispõhimõte. Vasakul jaama talitlus elektritarbimistipu ajal, paremal piirjuhtumil väljaspool tipuaega

Sellise hinnapoliitika rakendamine tõi kaasa ka investorite huvi koostootmisjaamade arendamise vastu, mis veerandsaja aasta jooksul on viinud Taani energeetikas suure hulga soojussalvestitega varustatud koostootmisjaamade ehitamisele. Nende hulgas on suuri, kuid on ka päris väikesi, nii et

Taanis võib juba tõsiselt rääkida *hajutatud elektritootmisest* ja *hajutatud elektrisüsteemist*.

Praegu on Taanis 285 elektri ja soojuse koostootmisjaama, mida võib lugeda hajutatud energiatootjate hulka. Sellele lisanduvad veel 380 ettevõtetele ja asutustele kuuluvat koostootmisjaama. Kokku on Taanis 26 suurema kui 10 MW võimsusega koostootmisjaama koguvõimsusega 690 MW, 55 jaama võimsusvahemikus 5 kuni 10 MW koguvõimsusega 360 MW ja 478 jaama elektrilise võimsusega alla 5 MW koguvõimsusega 515 MW. Kõigil neil on soojussalvestitena kasutusel veemahutid, kuid praegu on kõne all ka teiste, tõhusamate salvestite kasutamine. Üle poole Taani elektrienergiast toodetakse praegu koostootmisjaamades.

Enamik koostootmisjaamadest töötab maagaasil. Ülejäänutest kasutab 18 jaama jäätmeid, 10 jaama töötab õlgedel ja puiduhakkel, 30 jaama põletavad sõnnikust või muudest heitmetest saadavat biogaasi.

Alltoodud tabelis on esitatud mõnede Taani koostootmisjaamade võimsused ja soojussalvestite salvestusvõime koos nende täislaadimiseks vajaliku ajaga jaama maksimaalvõimsuse juures.

Jaam	Nimiväljundvõimsus MW		Salvesti veekogus m^3	Salvesti soojusmahtuvus		Täislaadimisaeg h
	Elektriline	Soojuslik		GJ	MWh	
Herning	89	174	35 000	4389	1219	7,0
Helsingor	60	60	16 000	2006	557	9,3
Hillerod	77	78	16 000	2006	557	7,1
Slagelse	12	28	3 500	439	121	4,4
Helsinge	6,7	6,1	1 350	169	46	6,2
Presto	5,6	6,2	1 050	132	37	5,9
Vejen	2,5	9,0	1 500	188	52	5,8

Suur soojussalvesti võimaldab koostootmisjaamas salvestisse mineva võimsuse muutmisega muuta ühtlasi jaama elektrilist võimsust. Energiasüsteemis tähendab see võimsuse reguleerimise lisavõimalust. Sellist reguleerimisviisi pakuvad Taani spetsialistid praegu nii enda energeetikutele kui ka teistele Euroopa riikidele elektrituulikute ebaühtlase talitluse tasakaalustamiseks. Koostootmisjaamade reguleerimisreservi saab müüa ka *reservide turul*.

Taanis on nii tuuleelektrijaamade osakaal elektrienergia tootmisel kui ka koostootmisjaamade olukord mõnevõrra erandlik. Teistes Euroopa riikides, kus tuuleenergia kasutamine kasvab praegu väga kiiresti, ei ole koostoomisjaamade energiasalvestid veel nii levinud ja ka kolmeastmelist energiatariifi ei ole kusagil mujal rakendatud.

Milline on olukord Eestis? Teada on, et meie koostootmisjaamades ühtegi energiasalvestit ei ole. Ei ole veel tekkinud ka majanduslikku huvi sellekohasteks investeeringuteks. Meie hinnapoliitika on selline, et praegu makstakse koostootmisjaamadele 81 senti taastuvatest energiaallikatest toodetud kilovatt-tunni eest ja 41 senti muudel juhtudel, sõltumata energia tootmise kellaajast ja kuupäevast. Selline süsteem ei erguta eriti kedagi millekski peale taastuvenergial põhinevate koostootmisjaamade rajamise. Tagajärjeks on loomulikult kõikvõimalike investorite surve üha suurema hulga ja suurema võimsusega tuuleelektrijaamade rajamiseks.

Taani eeskuju näitab, et ka meil oleks mõtet arutada senise süsteemi muutmise otstarbekust. Kui viia sisse kolmeastmeline tariif, siis millal ja milliste tulemusteni võiks see viia? Kas tuleks ehk teha mingi mudeleksperiment selle arenguvõimaluse uurimiseks? Või on otstarbekam investeerida elektrivõrkudesse ja jätta kogu tuuleenergia kõikumise tasakaalustamine Läti ja Venemaa hüdroelektrijaamade kanda? Või tuleks hoopis muuta toodetava elektrienergia eest tasumise süsteemi selliselt, et enam eelistatuks muutuks elektri tootmine mingist muust taastuvallikast peale tuule, aga ka uute tuuleelektrijaamade ehitamine ikkagi mõttekaks jääks?

Arutamise tahke paistab olema mitmeid. Nagu näiteks sellisedki küsimused, nagu suurte veebasseinide kütteseadmed – kas need ei võiks olla koostootmisjaamad? Peaks läbi arvutama ka soojussalvestite otstarbekuse nendes võimalikes koostootmisjaamades. Kui arvutustest peaks selguma midagi positiivset, võiksime hakata Euroopa pildis nüüdisaegsemalt välja nägema. Igal juhul tuleb need probleemid mitte läbi arutada, vaid läbi arvutada, arvestades seejuures ka Euroopa Liidu võimalikku rahalist toetust selliste projektide elluviimiseks. See on tähtis nii meile kui ka kõigile meie naabritele võimalikku atmosfääriõhu kaitset silmas pidades. Vajalikud uuringud ei ole võib-olla eriti mahukad, aga umbes miljon krooni oleks ehk nende jaoks vaja. Kes peaks olema see asutus, kes sellise töö telliks? Kas riik? Ja kui riik, siis milline ministeerium? Tegelikult sillutaks see nagu tulevikuteed elektrituulikutele ja järelikult võiks kaasata ka erakapitali. Või oleks ehk õigem ikkagi lootma jääda Euroopa Liidu rahadele ja oodata *DESIRE*-projekti jätkamist nimelt selles suunas? Vähemalt on see üks võimalustest, mida selles projektis osalejad ei tohi ära unustada.

Igal juhul vajab asi arutamist ja üks kohtadest, kus arvamusi avaldada, oleks ajakiri *Elektrialas*. Nii et – mis ja kuidas?

SUMMARY

The Lighting of State Symbols on Toompea Palace

Elektriala **8** (2006), No. 1, p. 9 (in Estonian)

A short description of the new installation for the lighting of the Coat of Arms and National Flag of Estonia at the front of Toompea Palace (the Estonian Parliament Building in Tallinn).

Ülo RUDI

The World Energy Council and Estonia

Elektriala **8** (2006), No. 1, pp. 10–11 (in Estonian)

Before World War II, the Estonian Power Committee was a Member of the World Energy Council (then the *World Power Conference*) established in 1923 in London. At the 17[th] Conference of the WEC held in Houston on 13 September 1998, Estonian membership in this international organization was restored, and on 16 July 2003 an Estonian National Committee of the WEC was established. In January 2006, Sandor Liive, Chairman of the Board of Eesti Energia, was elected as Head of this Committee. In September 2006 the WEC's annual Executive Assembly and at the same time an Estonian National Conference on Energy will be held in Tallinn.

Heiki TAMMOJA, Olaf TERNO

Cogeneration plants can compensate wind farm power imbalance

Elektriala **8** (2006), No. 1, pp. 12–13 (in Estonian)

The Danish experience of using heat accumulators in cogeneration power plants for load levelling in power systems and, in particular, for the compensation of the unstable power output of wind farms, is described.

Priit ARRO

The art expositions in KUMU are protected

Elektriala **8** (2006), No. 1, pp. 14–15 (in Estonian)

A report on the information technology, telecommunication, fire protection, evacuation and security systems of the new Estonian Art Museum, *'KUMU'* in Tallinn. For this purpose, over 100 various low current systems based on metallic or optical wiring and wireless communication have been installed.

A new product family from OBO Bettermann

Elektriala **8** (2006), No. 1, p. 19 (in Estonian)

Some new series of high-level installation switches and socket-outlets with good decorative design are introduced.

Indrek ROASTO

Programmable logic devices

Elektriala **8** (2006), No. 1, pp. 24–28 (in Estonian)

A detailed and well-illustrated popular review on the programmable logic devices that due to their flexibility are nowadays widely used for industrial and laboratory control circuits.

Dmitri Vinnikov – doctor of technical sciences

Elektriala **8** (2006), No. 1, p. 27 (in Estonian)

On 20 December 2005, researcher Dmitri Vinnikov, who obtained his Master's degree from Tallinn University of Technology in 2001, defended his doctoral thesis, entitled ***The Research, Design and Implementation of Auxiliary Power Supplies for Light Rail Vehicles*** at the Institute of Electrical Drives and Power Electronics of Tallinn University of Technology.

Meelis KÄRT

On electrical accidents in the year 2005

Elektriala **8** (2006), No. 1, pp. 28–30 (in Estonian)

A brief overview of the accidents caused by electricity in Estonian electrical installations during the year 2005. 11 cases, including 2 fatal electric shocks, are described.

Rein VÕRK

Reminescences on the expert examinations of electrical accidents

Elektriala **8** (2006), No. 1, pp. 30–31 (in Estonian)

Some examples of expert examinations performed by the author, who was an expert at the Estonian Laboratory of Court Expertise in 1970–1990s; on